MONTHLY WEATHER REVIEW

VOLUME 78 NUMBER 4

APRIL 1950

CONTENTS

U. S. DEPARTMENT OF COMMERCE · WEATHER BUREAU

NOTICE OF CHANGE IN MONTHLY WEATHER REVIEW

The monthly climatological data tables carried in the MONTHLY WEATHER REVIEW through December 1949 now appear in "Climatological Data, National Summary". The subscription price to "Climatological Data, National Summary" is 15 cents per copy or $1.50 per year; remittance (payable to Treasurer of the United States) and correspondence regarding subscriptions should be sent to Superintendent of Documents, Government Printing Office, Washington 25, D. C.

CORRECTIONS

MONTHLY WEATHER REVIEW, March 1950, vol. 78, p. 52; column 2, lines 19 and 20 should read: essential features in their theory of the formation of the "jet stream". Figure 3 shows . . .

p. 52, figure 2: Inverted map should be turned to correct position.

DEPARTMENT OF COMMERCE
CHARLES SAWYER, Secretary

WEATHER BUREAU
F. W. REICHELDERFER, Chief

MONTHLY WEATHER REVIEW

Editor, JAMES E. CASKEY, JR.

Volume 78
Number 4

APRIL 1950

Closed June 5, 1950
Issued July 15, 1950

FORECASTING WINTER PRECIPITATION FOR ATLANTA, GA.

ROBERT G. BEEBE

Weather Bureau Airport Station, Atlanta Ga.

[Manuscript received Nov. 4, 1949]

ABSTRACT

An objective method is presented for predicting the occurrence of winter time precipitation during the 24-hour period beginning at 0730 EST at Atlanta, Ga. Variables measuring moisture, temperature advection, and flow pattern from the 850- and 700-mb. pressure charts are combined through the use of scatter diagrams to determine the forecast. On independent data and in actual use, these forecasts are compared with the official forecasts for the same time and periods. The results show decided improvement in accuracy and skill as well as fewer large errors.

CONTENTS

INTRODUCTION

This study is primarily concerned not with an explanation of the causes of precipitation, but with an evaluation in somewhat more detail than has heretofore been done of the importance of some of the meteorological variables taken from the 850- and 700-mb. pressure charts that are associated with the subsequent occurrence of precipitation or no-precipitation at Atlanta, Ga. These variables are combined through the use of scatter diagrams to determine a forecast by an objective procedure. This method is not intended to make the forecast, but to serve the forecaster as an aid in quickly and easily evaluating some of the variables entering into his forecast. He must still call upon his judgment and experience in weighing and combining into a final forecast other factors which have not been considered here, such as the surface analysis, deepening or filling of systems, abnormal movements of systems, timing of precipitation occurrences, stagnant pressure centers, etc.

Visscher's [1] work on Gulf cyclogenesis is an extremely valuable aid in forecasting winter-time precipitation over the Southeastern States. And, since it is intended primarily to help forecast those situations which in the past have been the most bothersome, its usefulness is the more outstanding. There are, however, numerous cases of precipitation that are not accounted for in his work. Norton [2] has suggested numerous helpful subjective aids to the forecaster in this area and while these suggestions are good, they must be applied in conjunction with experience. Such subjective rules or aids cannot, in general, accurately indicate the relative weight to be applied to the different meteorological variables, and

889666—50

many cases are left open to question. Brier [3] has shown that a few, easily measured meteorological variables may be combined graphically in such a manner as to arrive at a rather good forecast through objective means. This investigation is roughly fashioned after his.

This study was made primarily to aid the forecaster making the forecast from the 0630 GMT surface map. The forecast period used is the 24-hour interval from 1230 GMT of the day the forecast is made to 1230 GMT of the next day. The data used to construct the diagrams were taken from the 850- and 700-mb. pressure charts at 0300 GMT. Forecast periods during which measurable precipitation (0.01 inch or more) in any form occurred at the station were classed as "precipitation" cases. The periods during which a trace or no rain was recorded were classed as "no-precipitation" cases.

Data from the two winter seasons (December, January, and February) 1945–46 and 1946–47, were used in preparing scatter diagrams, and data from the winter 1947–48 were used as test data. The diagrams were also tested on December 1948 and January 1949 data and by actual daily use during February 1949.

CLASSIFICATION OF CHARTS

There are at least three factors to be considered in making a forecast of precipitation: (1) available moisture, (2) means of moving it over the area in question, and (3) lifting to result in precipitation of the moisture. Because variables selected to measure these factors might not have the same significance in different meteorological situations, it seemed desirable to stratify the cases on a synoptic basis. Winter time precipitation at Atlanta may be of a number of different types depending on the synoptic situation, such as pre-cold-front rain, pre-warm-front rain, rain from developing Gulf waves, rain from stable waves along a cold front, etc. Although it would seem desirable to classify the precipitation according to some particular type of surface chart, it was the purpose of this study only to make use of upper air data, and therefore the stratification is based on 850- and 700-mb. charts.

Each upper air situation was classed as either a "strong gradient" or "weak gradient" type in order to incorporate some measure of the strength of airflow over the Atlanta area. The type of chart was determined solely from conditions at or in the vicinity of Atlanta. A "weak gradient" chart was loosely defined as one in which the wind speed at Atlanta was Beaufort force 3 or less, *or* which had an indefinite or irregular spacing of the height contour lines (such as near high centers or cols) in the Atlanta area. A "strong gradient" chart was one in which the wind speed at Atlanta was Beaufort force 4 or stronger *and* which had a regular or definite spacing of the height contour lines in the Atlanta area. In classifying these charts, no consideration was given to what the wind speed or contour lines might be at any future time. A date was classed as a "strong gradient" case if both the 850- and 700-mb. charts were of the "strong gradient" type and as a "weak gradient" case if either, or both, of the constant pressure charts was classed as a "weak gradient" type. This is a rather subjective and nonrigid classification. However, the simplicity aided greatly in the construction of diagrams to fit each type and few cases were found in which the application of the definitions was questionable. It was found that a different set of diagrams, using different variables, was needed to give good results for each of these two types. Although two sets of diagrams are needed, only one of these sets is used on any particular date to make a forecast by this method.

STRONG GRADIENT CASES

METEOROLOGICAL VARIABLES

Several variables that could be considered as measures of moisture, moisture advection, and lifting were investigated and various methods of combining them in scatter diagrams were tried on the "strong gradient" cases, but those described below produced the best results. The dew point at a point upstream from Atlanta at 850 mb. was utilized as a measure of moisture at that level, and the temperature difference at 850 mb. measured from Atlanta to the point upstream, as a measure of lifting. To determine the upstream point to use in measuring the 850-mb. temperature difference and dew point, the height contour line through Atlanta was followed upstream to a point between or near the first of the following radiosonde stations encountered: Nashville, Little Rock, Lake Charles, New Orleans, Appalachicola, Charleston, or Greensboro. Since radiosonde observations only rarely fall exactly on the contour line, estimates were made by interpolation and/or use of the analysis of the isotherms. If, for example, the contour line through Atlanta passed through a point 100 miles south of Nashville but then curved southward so that it passed through Lake Charles, the point at which the temperature difference was determined was the point nearest Nashville. Exceptions to this rule were made in cases in which a trough existed west of Atlanta but east of any of the radiosonde stations mentioned. In these cases, the contour line was followed only to the trough line. Temperature difference as used in this study is simply the 850-mb. temperature at Atlanta minus the 850-mb. temperature upstream. The dew point was estimated at the same upstream point at the 850-mb. level. "Motor boating" humidities were considered as zero amounts of moisture regardless of the temperature.

At the 700-mb. level the dew point upstream from Atlanta, determined in the same manner as described for the 850-mb. data, was likewise used to measure the moisture. A measure of moisture advection, lifting, and a classification of the 700-mb. chart types is provided by the latitude of the 700-mb. height contour line upstream from Atlanta [3]. Suppose, for example, the contour line passes through New Orleans and reaches a minimum lati-

tude of 25° N. but the mixing ratio is very low. The dew point value, if used alone, might indicate only a slight probability of precipitation, but with a flow of air from the Gulf, the moisture values are likely to be much higher a little further upstream. On the other hand, suppose there has been extensive precipitation associated with a deep low north of Atlanta. The 700-mb. dew point value may be high and thus indicate a high probability of precipitation. But if the contour line goes to high latitudes, a strong ridge of high pressure to the west is indicated which precludes this high probability. Thus, the latitude of the 700-mb. height contour line also provides a numerical index of the chart type. Values of 20° N. usually indicate a warm high in this area; values greater than 37° N. indicate a strong ridge of high pressure to the west; and values between 33° N. and 37° N. usually indicate a westerly flow over this area.

In determining the latitude of the 700-mb. height contour line upstream from Atlanta, the contour was not followed beyond 100° W. In cases in which the height contour line passed through Atlanta in a direction between 280° and 360°, the value of the latitude was taken at the crest of the first ridge west of Atlanta or at 100° W. if the ridge was west of this meridian. If a closed low center existed east of Atlanta, the contour line was followed upstream to the highest latitude. In all other cases, the contour line through Atlanta was followed upstream to the lowest latitude east of the 100° W.

SCATTER DIAGRAMS

The data at 850 mb. were combined into a scatter diagram [1] and lines of equal relative frequency of precipitation were drawn as shown in figure 1. In analyzing this diagram for probability of precipitation the meteorologist might expect that with some lifting (warmer upstream and negative values of temperature difference) the probabiltiy of precipitation would be large if moisture were available. And, with no lifting (colder upstream) the probability of precipitation would become very small regardless of moisture. Further, with very strong lifting, the probability of precipitation would become large even with low humidities. Also, in this latter case, a strong negative temperature gradient indicates a strong flow or strengthening of present flow of air over the area. Thus, one might expect that with large values of negative temperature gradient, the probability of precipitation would be high regardless of present moisture. The lines of probability on figure 1 are drawn in accord with these hypotheses, that is, vertical (independent of dew point values) both for large positive temperature gradient values and for large negative temperature gradients. Between these extremes, the lines of probability will depend both upon the amount of available moisture and the temperature gradient and will connect with the previously mentioned extremes. The data plotted in figure 1 seem to justify this reasoning. Throughout this investigation dashed lines of equal probability are used in areas of the scatter diagrams where the analysis is somewhat uncertain.

Figure 2 is the scatter diagram prepared from the data at 700 mb. and analyzed by drawing lines of equal relative frequency of precipitation. For latitude values greater than 34° N. (northerly flow into Atlanta), it should be expected that the probability of precipitation would be very small, regardless of moisture. And even those cases with precipitation should show small amounts due to showers or precipitation beginning very late in the forecast period. With lower latitude values, say 25° to 30° N., the probability should increase and be dependent upon moisture values. However, with very low latitude values, say 20° N., the probability should again decrease but still be dependent upon moisture values. This is due to the chart type implied in these latitude values of the contour line. That is, with a latitude value of 20°, the contour line passes far south of Atlanta and is probably due to the influence of the Bermuda High rather than to a trough west of Atlanta. Thus, it should be expected that lines of probability of precipitation would be curved and dependent upon moisture except that those cases with a strong ridge to the west will be independent of moisture with small probability of precipitation.

These two scatter diagrams were then combined (probabilities from data at 850 mb. (fig. 1) plotted against those at 700 mb. (fig. 2) for each date) into the final diagram shown in figure 3 to give the forecast for "strong gradient" cases. A "forecast" line was drawn on this combined diagram to give the best forecast for all cases, and which, at the same time appeared to be consistent with the analysis of the previous two scatter diagrams. Of the 6 months of original data,[2] there were thirteen errors in 140 cases. That is, 91 percent of the "forecasts" were correct.

EXAMPLE

An example of a "strong gradient" case that occurred on January 28, 1949, is shown in figures 4 and 5. It is classed as a "strong gradient" case because the gradient at *both* the 850- and 700-mb. levels is definite and the winds are stronger than force 3 at Atlanta. On the 850-mb. chart, the temperature difference upstream is −2° C. (11°−13° C.) and the dew point at that same point is 8° C. These data entered on figure 1 show a probability of precipitation of 78 percent. At the 700-mb. level, the dew point is 3° C. and the lowest latitude of the contour line through Altanta is about 27.5° N. From figure 2, these data indicate a probability of 95 percent. And from

[1] The scatter diagrams in figs. 1, 2, and 6 have nonlinear scales in dew point. However, the scales are linear in terms of mixing ratio, the humidity quantity on which the diagrams were originally based. Conversion to dew point was to conform with the present practice of plotting dew point on upper air charts. A mixing ratio scale is also given for use with upper air charts on which mixing ratio is plotted.

[2] Both original (dependent) and test (independent) data are plotted on the scatter diagrams, figs. 1, 2, 3, and 6. (See p. 67).

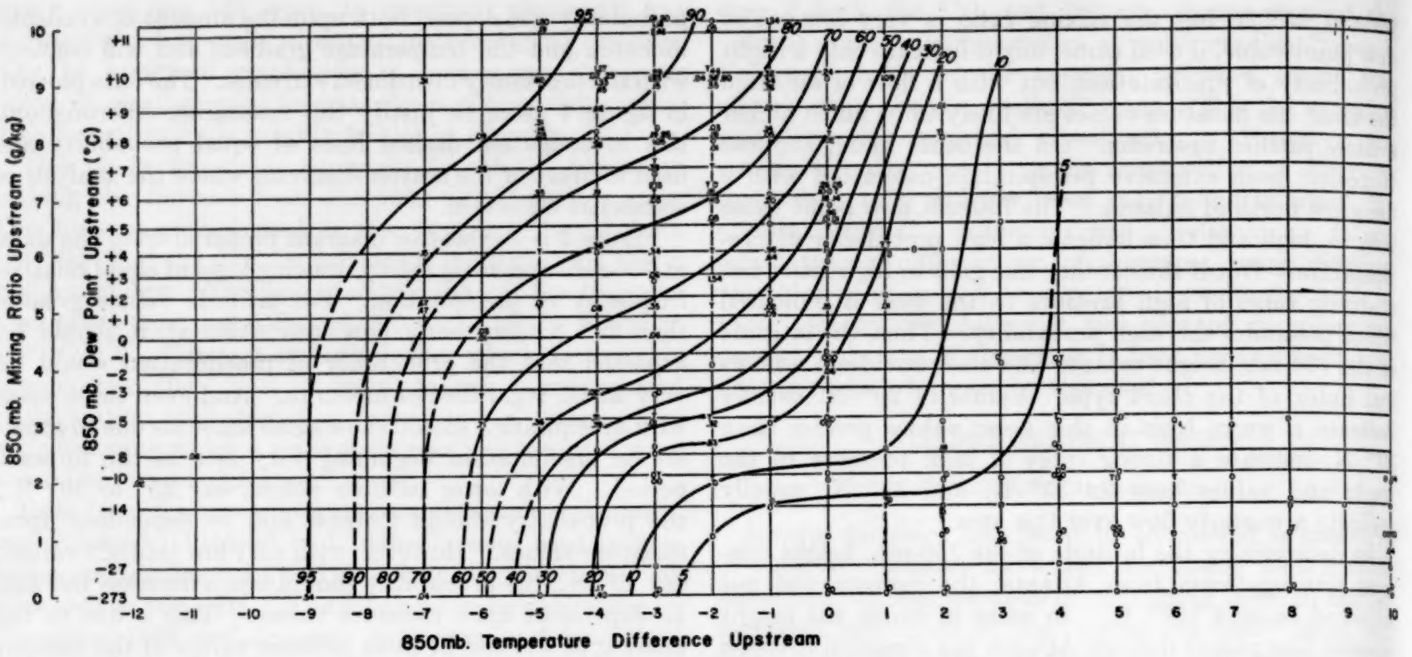


FIGURE 1.—Chart showing probability of precipitation for "strong gradient" cases from four seasons of data. Observed precipitation amount is plotted as a function of 850-mb. dew-point (or mixing ratio) upstream and 850-mb. temperature difference upstream.

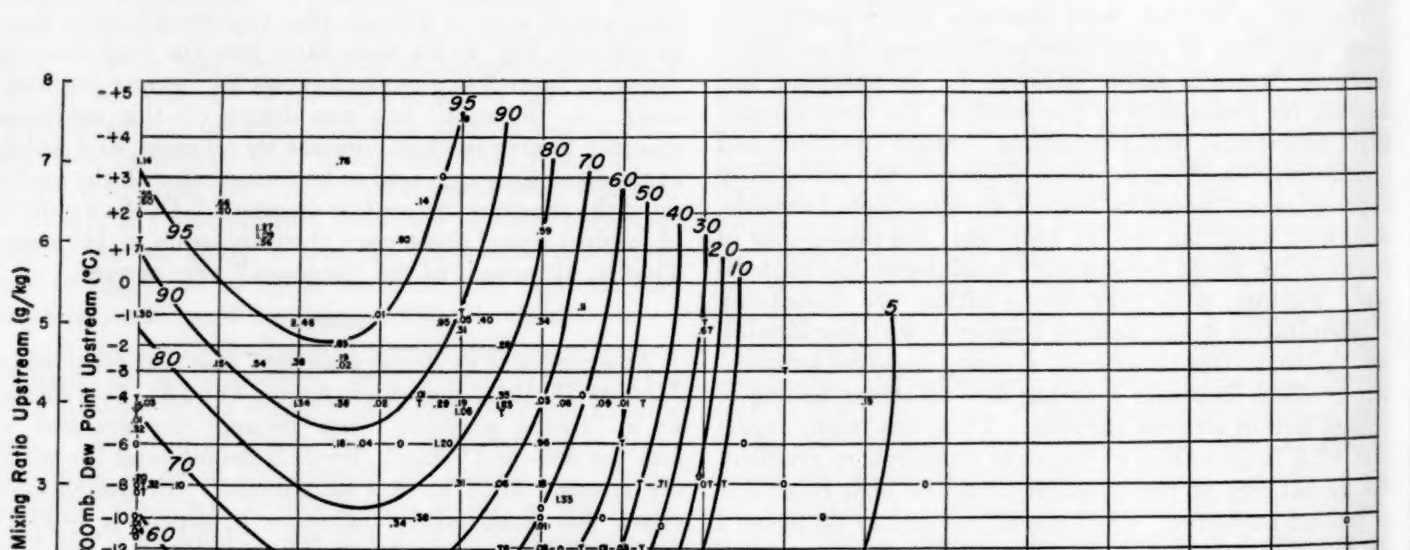


FIGURE 2.—Chart showing probability of precipitation for "strong gradient" cases from four seasons of data. Observed precipitation amount is plotted as a function of 700-mb. dew point (or mixing ratio) upstream and latitude of the 700-mb. height contour line through Atlanta.

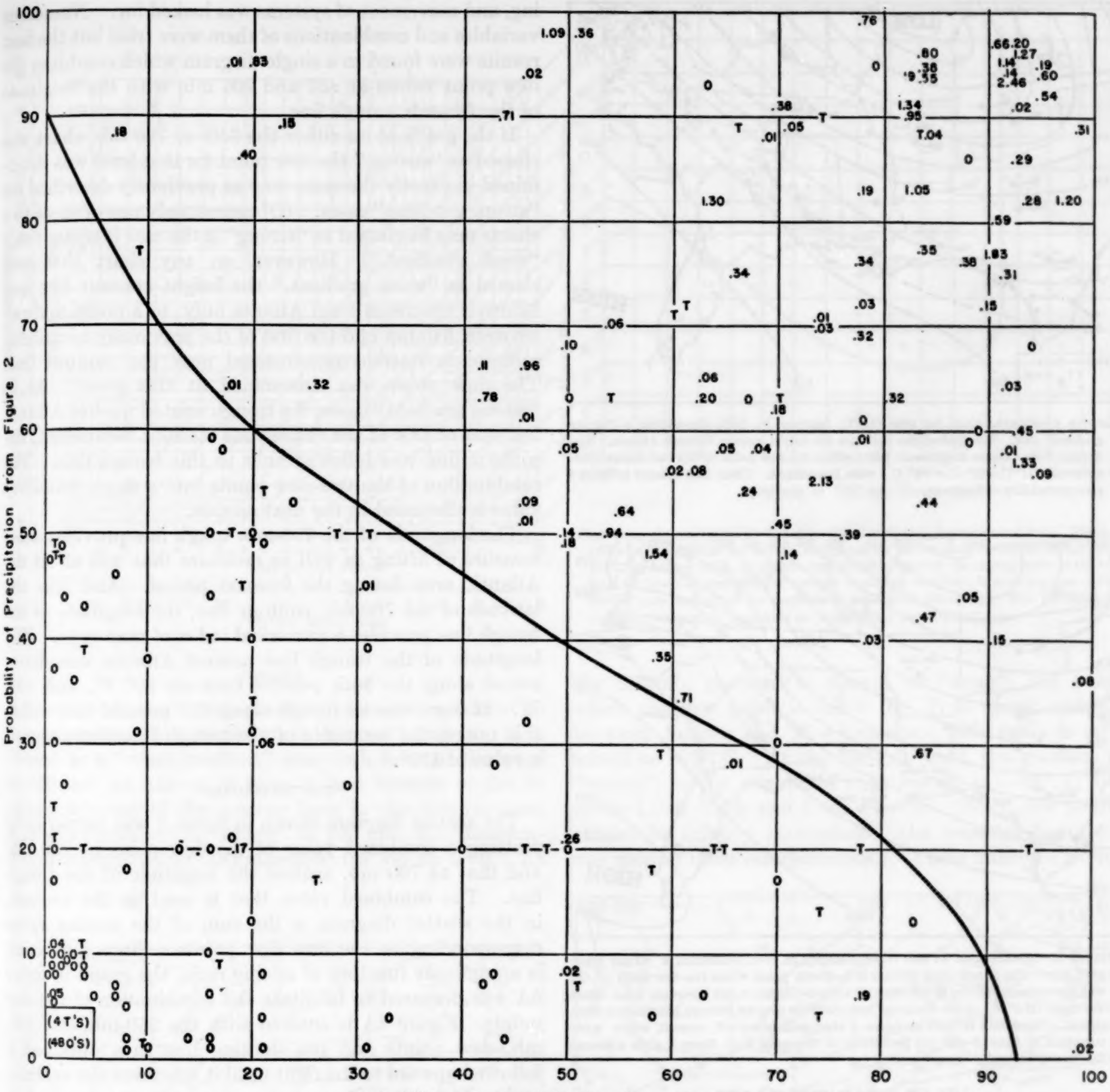


FIGURE 3.—Forecast chart for "strong gradient" cases combining figure 1 and figure 2. The line separates precipitation cases (upper right) from no-precipitation cases (lower left) plotted as a function of the probability based on the 850-mb. data and that based on the 700-mb. data.

figure 3, these probabilities give a forecast for precipitation. However, none occurred. This example is one in which subjective considerations can improve upon the forecasts from the diagrams alone. Note that at the 850-mb. level the temperature and the humidity are much lower just west of the point where the data were taken. Since the winds are quite strong, this dry, cool air will reach Atlanta very soon. Also, note that at the 700-mb. level the moisture values drop off rapidly west of New Orleans and again the winds are strong.

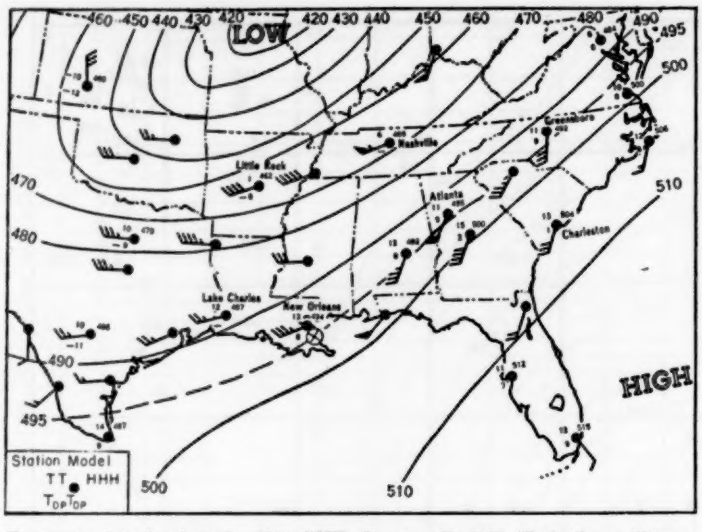


FIGURE 4.—850-mb. chart for 0300 GMT, January 28, 1949, illustrating a "strong gradient" case. The dashed line indicates the height contour through Atlanta. The ⊗ near New Orleans is upstream point where the dew point (8° C.) and temperature difference (11° C.−13° C.=−2° C.) were determined. These data entered in figure 1 give probability=78 percent.

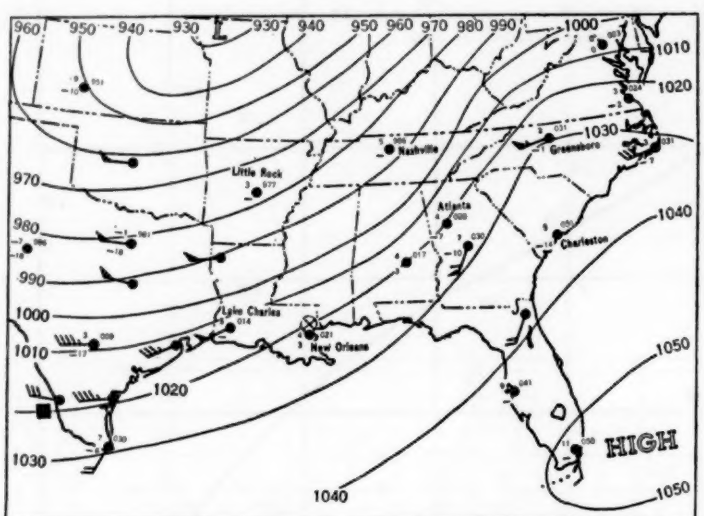


FIGURE 5.—700-mb. chart for 0300 GMT, January 28, 1949, illustrating a "strong gradient" case. The ⊗ near New Orleans is upstream point where the dew point (3° C.) was determined, and the ■ just west of Corpus Christi is the upstream point where the value (27.5° N.) of the minimum latitude of the contour through Atlanta was determined. These data entered in figure 2 give probability=95 percent, which when combined in figure 3 with the probability of 78 percent from figure 1, gives a forecast for "precipitation."

WEAK GRADIENT CASES

METEOROLOGICAL VARIABLES

A height contour line does not have the same significance in the cases of irregular or indefinite spacing of the contour lines on the constant pressure charts as it does in the "strong gradient" cases. That is, in "strong gradient" cases, future advection may be approximated by following a contour line upstream. However, in the case of "weak gradients," small changes in height may change the height contour pattern so that following height contour lines upstream in these cases is of little or no prognostic value. Therefore, some other means of measuring moisture, lifting, and movement of systems was looked for. Numerous variables and combinations of them were tried but the best results were found in a single diagram which combines the dew point values at 850 and 700 mb. with the longitude of the 700-mb. trough line.

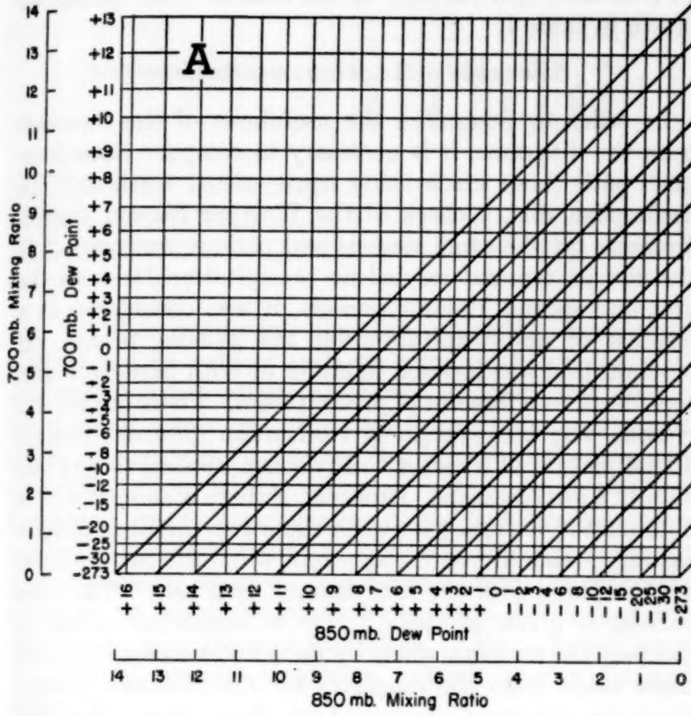
If the gradient on either the 850- or 700-mb. chart was classed as "strong," the dew point for that level was determined in exactly the same way as previously described for "strong gradient" cases. (Of course, only one of these two charts may be classed as "strong" if the case is treated as a "weak gradient.") However, on any chart that was classed as "weak gradient," the height contour line was followed upstream from Atlanta only, to a point midway between Atlanta and the first of the previously mentioned radiosonde stations encountered near the contour line. The dew point was determined at this point. As in "strong gradient" cases, if a trough existed west of Atlanta but east of any of the radiosonde stations mentioned, the contour line was followed only to this trough line. The combination of the two dew points into a single humidity value is discussed in the next section.

The longitude of the 700-mb. tough line provides some measure of lifting as well as moisture that will affect the Atlantic area during the forecast period. And, like the latitude of the 700-mb. contour line, the longitude of the trough line provides a numerical index of map type. The longitude of the trough line nearest Atlanta was determined along the 34th parallel between 80° W. and 120° W. If there was no trough along this parallel and within this range, the longitude of the trough line was assigned a value of 120°.

SCATTER DIAGRAM

The scatter diagram shown in figure 6 was prepared by plotting a combined value of the dew point at 850 mb. and that at 700 mb. against the longitude of the trough line. The combined value that is used as the ordinate in the scatter diagram is the sum of the mixing ratios corresponding to the two dew points. Since dew point is a nonlinear function of mixing ratio, the graph in figure 6A was prepared to facilitate the combination of the dew points. Figure 6A is entered with the 850-mb. and 700-mb. dew points and the slanting line thus obtained is followed upward to the right until it intersects the ordinate scale which gives the mixing ratio value to be used in entering the scatter diagram, figure 6B.

After the data had been plotted on the scatter diagram, a "forecast" line was drawn by inspection to best separate precipitation cases from those in which no precipitation occurred. At longitude 88.5° W. and less, it may be noted that the forecast depends solely upon the longitude and is independent of moisture. That is, if a trough is already east of this meridian, it will normally move on through so that no precipitation falls at Atlanta during the forecast period. There was 1 error in the 40 dependent cases, or about 98 percent of the cases were on the correct side of the "forecast" line.



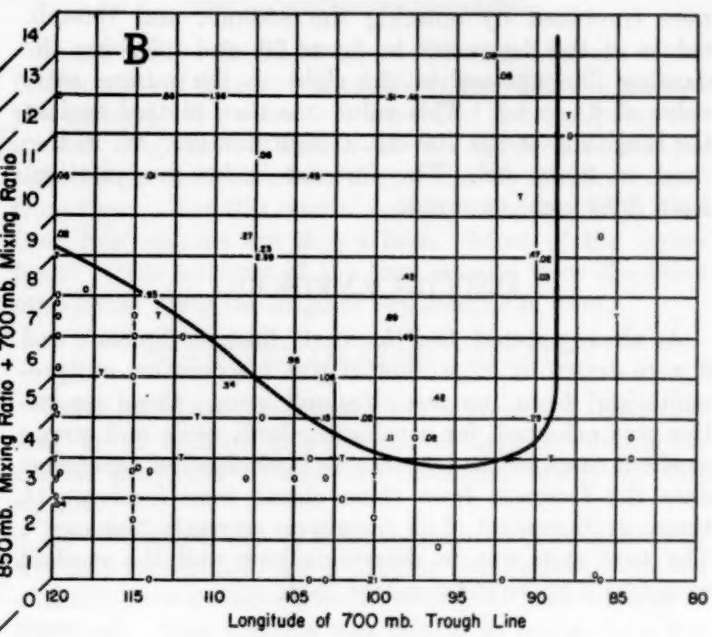


FIGURE 6.—Forecast chart for "weak gradient" cases from four seasons of data. Chart A graphically combines the 850-mb. dew point (or mixing ratio) with the 700-mb. dew point (or mixing ratio), giving the sum (slanting lines) of the mixing ratios at the two levels. Observed precipitation amount is plotted on Chart B as a function of this mixing ratio sum and of the longitude of the 700-mb. trough line. The line separates precipitation cases (above) from no-precipitation cases (below).

EXAMPLE

An example of a "weak gradient" case that occurred on December 24, 1947, is shown in figures 7 and 8. It is classed as a "weak gradient" case both because the wind at 850 mb. at Atlanta is force 2, and because of the irregular spacing of the contour lines in the Atlanta area. While the gradient is "strong" at 700 mb., the classification is determined by the gradient at the weaker level. As the 850-mb. gradient is classed as "weak", the point where the dew point is taken (fig. 7) is about midway between Atlanta and New Orleans. This value is estimated as —3° C. At the 700-mb. level, the gradient is "strong", so the dew point is estimated as —24° C, between Little Rock and Lake Charles. (Since dew points cannot be linearly interpolated, the scale on figure 6A was used in these interpolations.) These moisture values

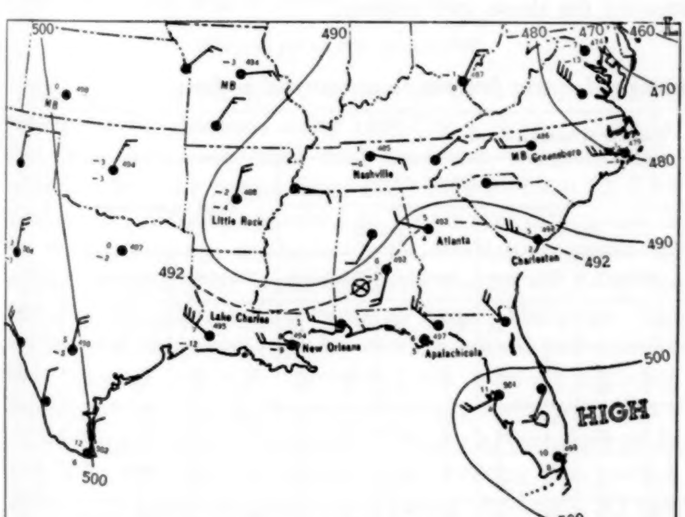


FIGURE 7.—850-mb. chart for 0300 GMT, December 24, 1947, illustrating a "weak gradient" case. The dashed line indicates the height contour through Atlanta. The ⊗ is the upstream point where the dew point (—3° C.) was estimated.

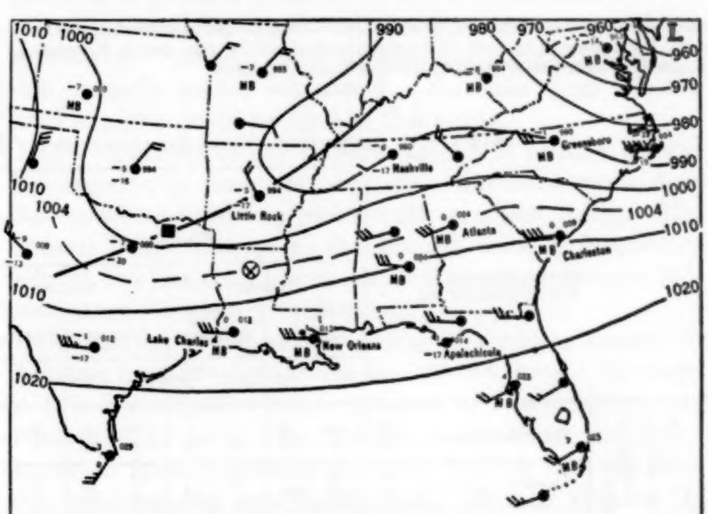


FIGURE 8.—700-mb. chart for 0300 GMT, December 24, 1947, illustrating a "weak gradient" case. The dashed line indicates the height contour through Atlanta. The ⊗ on this contour is the upstream point where the dew point (—24° C.) was estimated. The ■ along the trough line is the point where the longitude value (96° W.) was taken. These values together with the —3° C. dew point taken from 850-mb. chart (fig. 7, when entered in figure 6 give a forecast for "precipitation".

were combined by entering the 850-mb. and 700-mb. values of the dew point in figure 6A and following the slanting line upward to the right to the mixing ratio value of 4.4 gr/kg. This value was then plotted against the longitude of the 700-mb. trough line (96° W. in this case) in figure 6B. The forecast is for precipitation. Rain (0.42 inch) occurred.

RESULTS OF METHOD

As already stated, the "forecast" lines on figures 3 and 6 were drawn by inspection to give a separation of "precipitation" from "no-precipitation" cases. Good separation was achieved, for considering both weak and strong gradient cases for the two seasons (180 cases) of dependent data the forecasts from these charts were incorrect 14 times, or 92 percent of all cases were correctly "forecast". The next step was to determine how well the method would hold up on independent data.

TESTS ON INDEPENDENT DATA

This forecasting scheme was tested on independent data from the 3 months of the 1947–48 winter season. The diagrams produced three incorrect forecasts in 72 strong gradient cases and 2 incorrect forecasts in 28 weak gradient cases. This is an accuracy of 94 percent with a skill score [3] of 0.89. The errors were all caused by forecasts for precipitation when none occurred. This method was in actual use during February 1949 and was also tested on December and January of this season. The results are shown in table 1.

COMPARISON WITH CONVENTIONAL FORECASTS

In order to determine the usefulness of the forecasts from the diagrams, it is necessary to compare these forecasts with those made using conventional methods. To accomplish this, a check of the Weather Bureau district forecasts for the same seasons and periods was made. If the district forecast carried no precipitation for both the first and second 12-hour periods, it was considered as a forecast of no-precipitation for the 24-hour period. If precipitation was forecast in either or both periods, it was considered as a forecast of precipitation. There are several reasons why this system of verification does not present a true picture of forecast ability when applied to any one or only a few forecasts. However, if there is an appreciable difference in accuracy between these two methods of forecasting, it should become apparent when the two methods are compared over the four seasons used here. The comparison is given in table 1. It is somewhat unfair to compare the forecasts made by the district forecasters with those made from the diagrams for the first two seasons since the diagrams are based on these data. For this reason, skill scores were not computed for these seasons.

It is important that any objective forecasting method result in consistently good forecasts and not be subject to large variations in accuracy from time to time. It is significant that there was no month in which the forecasts made from the diagrams were in error as many times as the official forecasts. Thus, the diagrams give consistently good results even though there are monthly and seasonal variations. And, while the results from the independent data indicate some lessening of accuracy, the accuracy of the official forecasts decreased an even larger over-all amount for these two seasons.

[3] The skill score, S_e, as used here is defined as

$$S_e = \frac{C - E_e}{T - E_e}$$

where C = number of correct forecasts, E_e = number of forecasts expected to be correct due to chance, and T = total number of forecasts. The value of E_e for forecasts of "precipitation" and "no-precipitation" is given by

$$E_e = P \times F_r + N(1 - F_r)$$

where P = number of forecasts of "precipitation" during the period covered by the forecasts, N = number of forecasts of "no-precipitation" during this period, F_r = relative frequency of occurrence of precipitation cases during this period.

TABLE 1.—*A comparison between forecasts from the diagrams and district forecasts by conventional methods*

*P = Precipitation N = No precipitation		Number of forecast cases																			
		Dependent								Independent								Total for 4 seasons			
		1945–46				1946–47				1947–48				1948–49							
		District		Diagrams		District		Diagrams		District		Diagrams		District		Diagrams		District		Diagrams	
	*	P	N	P	N	P	N	P	N	P	N	P	N	P	N	P	N	P	N	P	N
Number of observed cases	December P	12	0	11	1	3	4	6	1	7	8	15	0	9	4	13	0	31	16	45	2
	December N	6	13	0	19	1	23	2	22	0	16	0	16	1	17	4	14	8	69	6	71
	January P	14	1	14	1	11	4	14	1	9	2	11	0	5	5	9	1	39	12	48	3
	January N	4	12	1	15	1	15	2	14	4	15	1	18	3	18	6	15	12	60	10	62
	February P	8	1	7	2	4	3	5	2	8	4	12	0	5	6	9	2	25	14	33	6
	February N	4	15	1	18	1	20	0	21	4	13	4	13	1	16	1	16	10	64	6	68
	Total for season P	34	2	32	4	18	11	25	4	24	14	38	0	19	15	31	3	95	42	126	11
	Total for season N	14	40	2	52	3	58	4	57	8	44	5	47	5	51	11	45	30	193	22	201
Percent correct		82		93		84		91		76		94		78		84		80		91	
Skill score		------		------		------		------		.49		.89		.50		.68		------		------	

TABLE 2.—*A summary of the comparison between precipitation amounts missed by the forecast diagrams and those by conventional methods when no precipitation was forecast*

Precipitation observed	1945-46		1946-47		1947-48		1948-49		Total	
	District	Diagrams	District	Diagrams	District	Diagrams	District	Diagrams	District	Diagrams
>.99 inch	—	—	—	—	—	—	2	—	2	—
.99-.50	—	—	—	—	2	—	2	1	4	1
.49-.25	—	—	2	—	4	—	3	1	9	1
.24-.10	1	2	4	1	2	—	1	—	8	3
.09-.01	1	2	5	3	6	—	7	1	19	6
Total errors	2	4	11	4	14	0	15	3	42	11

It is also important that an objective forecasting method not be subject to large errors. If, for example, the increased percentage of correct forecasts was due to fewer small errors, an objective forecast aid still might not be a help to the forecaster. Table 2 shows the amounts of precipitation which occurred with no-precipitation forecasts. Again, a comparison of the first two seasons is not valid, but it is shown to illustrate the differences by amounts and by seasons. The forecasts from the diagrams result in no large variations by seasons or between the dependent and independent data. Also, fewer large amounts of precipitation were missed by the forecast diagrams.

One of the most important facts shown by the analysis of incorrect forecasts made by using the diagrams is that during the four winter seasons, only twice when the forecast (from the diagrams) was "no rain" did rain begin before 1930 EST of that day. This is a very important feature because it virtually eliminates cases of rain beginning during the day when none had been forecast. And at the same time, this method does not result in a disproportionately large number of incorrect forecasts for precipitation. On the other hand, the district forecasts had 22 errors due to a "no-precipitation" forecast when measurable rain began before 1930 EST.

RESULTS FROM 1500 GMT DATA

The question naturally arises as to whether similar results can be obtained using 1500 GMT data. Data for this time were compiled and analyzed independently, using the 24-hour period from 1930 EST to 1930 EST for verification. There appeared to be no real differences in the patterns of the analyses on the scatter diagrams for either the strong or weak gradient cases. In fact, the patterns and probabilities were so nearly the same that the original diagrams may be used in actual practice for both forecast periods. Actually, the over-all accuracy appears to be a little better, although there was also a slight increase in the accuracy of the official forecasts made from the 1830 GMT surface maps covering this period. Obviously, forecasts made at 12-hour intervals by this method would provide a "timing factor" which would enable the forecaster to place the beginning of rain in the proper 12-hour period.

RESULTS OF INCREASING SAMPLE SIZE

Better results should be expected through the use of the four seasons of data now available rather than the original two seasons. So, these data were used in reanalyzing the scatter diagrams. There were no significant changes either in the analysis of the diagrams or in the "forecasts" from them. For this reason, only the diagrams with data from four seasons are shown here. Most of the errors found in the analysis of the four seasons were the same ones found using the original two seasons of data.

OTHER VARIABLES INVESTIGATED

Other variables investigated in the course of this study may be of interest to other meteorologists working on similar problems. These are discussed briefly in this section.

An attempt to obtain some measure of development of waves or lows in the Gulf of Mexico was made through use of the 12-hour sea level pressure change at Lake Charles or Burwood. This variable was helpful in many cases but frequently it was completely misleading. When, for example, a cold front moves rapidly from the north to the Gulf, the 12-hour pressure changes show large positive values. But, in many cases, the front stagnates and active over-running occurs over the southeastern states within the 33-hour period from the time of the sounding to the end of the verification period. Also, there was no apparent relation between the distance the front would move over the Gulf of Mexico and the magnitude of the 12-hour pressure rise behind a cold front moving out over the Gulf, the 12-hour pressure falls ahead of it, and the distance the 12-hour pressure rise center had moved. Thus, in this study the 12-hour pressure changes were of no use.

Surface dew points upstream from Atlanta were investigated as a possible measure of warm front activity, but they apparently contributed nothing more than mixing ratios aloft. And in cases of rapid movement of systems, this variable reacts too slowly. No data from the sea level analysis could be used in this study.

The longitude of the 700-mb. trough is usually helpful but apparently does not contribute anything more than the variables used except in weak gradient cases. The 12-hour height change at the 700-mb. level is frequently helpful, but like the 12-hour sea level pressure changes, it is sometimes completely misleading.

Continuous precipitation during the winter season in this area usually starts above the 700-mb. level. So, early in this investigation some measure of over-running was attempted by using the 700-mb. temperature difference upstream from Atlanta in the same manner that the 850-mb. temperatures were finally used. But, as Visscher [1] suggests, the 850-mb. analysis is apparently much more useful in forecasting precipitation in this area. Indeed, only a small improvement (about 5 percent) was found here by combining data taken from both the 850- and 700-mb. analyses.

CONCLUSIONS

This investigation clearly shows that improved precipitation forecasts for the Atlanta area can result from systematic utilization of 850- and 700-mb. data. Comparing the results of this study with official district forecasts indicates that the percentage of correct precipitation forecasts during the winter season may be increased by about 10 percent through the use of this method. At the same time, and of even greater importance, this forecasting method shows definite improvement in forecasting those cases of large amounts of precipitation. Since it is especially accurate during the first 12-hour period, its usefulness is again demonstrated by the rare occasions when precipitation does occur on a no-precipitation forecast. Apparently, from these four seasons of data, there is no appreciable change in the analysis of the scatter diagrams nor in the accuracy of the forecasts from them, by adding two more seasons of data and reanalyzing the scatter diagrams. Thus, it would seem that any increase in the sample size will not materially affect the results of this investigation.

One weakness of this method of forecasting precipitation is the manner of evaluating the advective temperature and dew point. Somewhat better results might be obtained by giving more consideration to wind speeds aloft. In cases of weak or indefinite pressure gradients, following a contour line upstream is not always representative of the probable advective change. If a stagnant or slow-moving high is over the Atlanta area with high humidities, a forecast for precipitation is sometimes in error. This latter example is the most frequent cause of an incorrect forecast of precipitation by this method. And, even though the gradient is strong and smooth, there will be errors due to stagnant systems or rapid movement. However, these conditions will usually be apparent to the forecaster and at any rate it is believed that further complication of the method to obtain a very small increase in accuracy is not justified. Subjective considerations, such as experience or suggestions given in this paper, should add further to the improvement of precipitation forecasts during the winter season at Atlanta.

ACKNOWLEDGMENTS

The author has received valuable assistance from Miss Obie Y. Causey throughout this investigation. Particular credit is due for her initiative in developing figure 6 on weak gradient cases. The suggestions and encouragement given by Mr. John C. Ballard were of considerable help in carrying on this investigation and the subsequent writing of this report.

REFERENCES

1. H. B. Visscher, *The Formation of Extratropical Cyclones in the Gulf of Mexico and the Resultant Spread of Precipitation*, Meteorological Department, Eastern Air Lines, Inc., Atlanta, Ga., 1948.
2. Grady Norton, "Some Notes on Forecasting for Atlanta and Miami Districts (North and South Carolina, Georgia, and Florida)", Weather Bureau *Research Paper No. 15*, Washington, D. C., 1944.
3. G. W. Brier, *Predicting Occurrence of Winter Time Precipitation for Washington, D. C.*, U. S. Weather Bureau, Washington, D. C., 1945.

THE WEATHER AND CIRCULATION OF APRIL 1950[1]

JAY S. WINSTON
Extended Forecast Section, U. S. Weather Bureau
Washington, D. C.

The basic pattern of the upper level circulation during April 1950 over North America consisted of a deep trough in eastern sections and a ridge in western sections of the continent (fig. 1). 700-mb. heights in the trough were below normal from James Bay southward to Florida and above normal east of Hudson Bay. These height anomalies were also extensive in a longitudinal direction on either side of the trough with negative departures stretching at middle latitudes (30°–50° N.) from the western Atlantic Ocean to the Plains States, and with positive departures extending zonally from central Canada to southern Greenland. In the ridge 700-mb. heights were above normal in northwestern Canada and along the Pacific coast of the United States south of 45° N., and below normal in southwestern Canada. Also of direct importance in its effects on United States weather was the deep low in the Gulf of Alaska and the trough to its south. Below-normal heights in this low, combined with positive height anomalies in the ridge along the Pacific coast, led to stronger-than-normal maritime flow into Washington, Oregon, and British Columbia.

Some other features of the circulation are of interest, although their influence on the United States area was not very significant during April. These were the extensive ridge in the Atlantic Ocean and the deep trough in western Europe and northwestern Africa. The split westerlies in mid-Atlantic, with the northern branch of the flow between about 50° and 70° N. and the southern branch at about 25° to 35° N. going into Africa, were indicative that this ridge was of a blocking type. The

[1] See Charts I-XI following p. 74 for analyzed climatological data for the month.

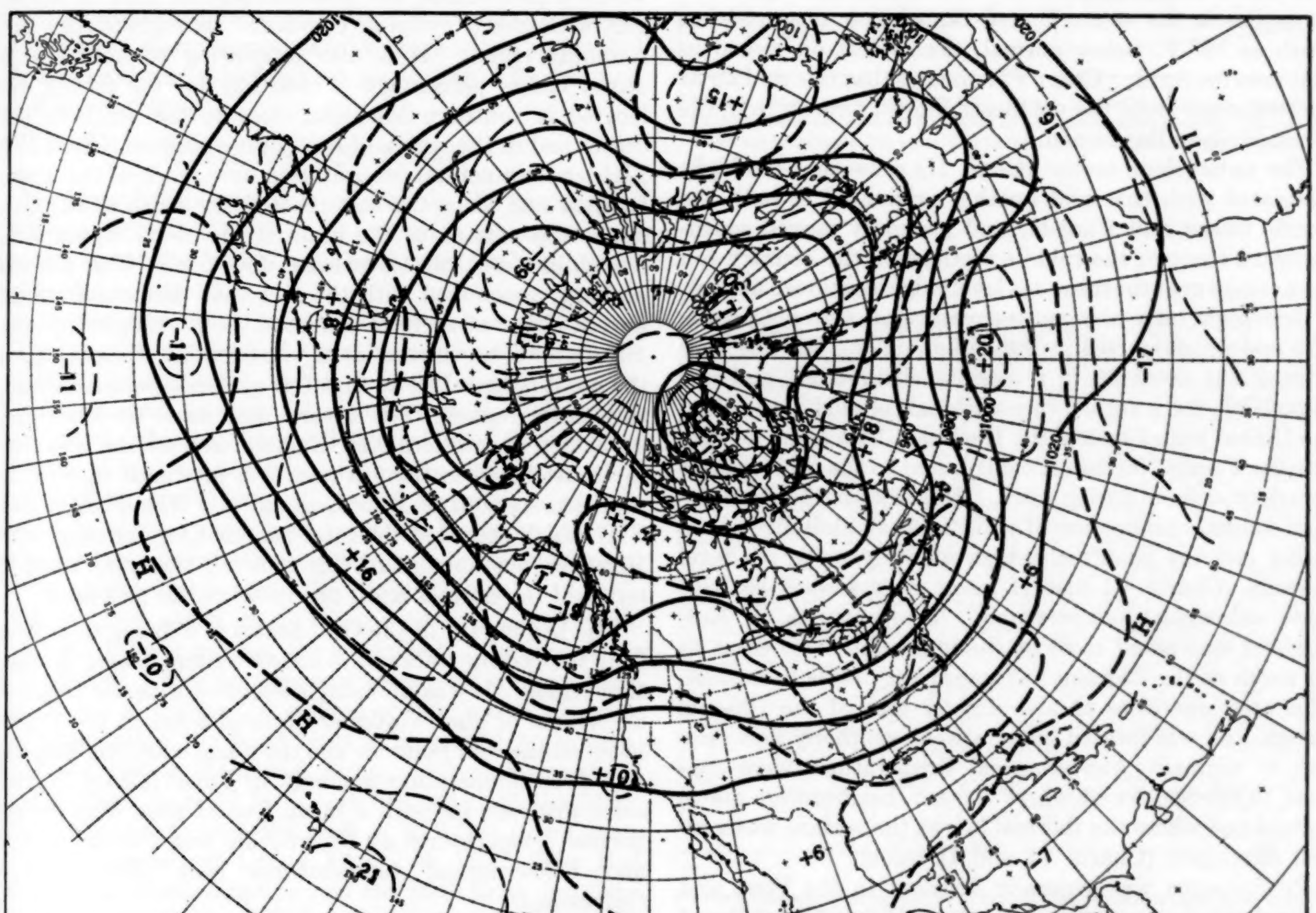


FIGURE 1.—Mean 700-mb. chart for the 30-day period March 28 to April 26, inclusive. Contours at 200-foot intervals are shown by solid lines, 700-mb. height departure from normal at 100-foot intervals by dashed lines with the zero isopleth heavier. Anomaly centers and contours are labeled in 10's of feet.

positive height center at 45° N., 30° W. was directly north of a negative height center at 30° N. Thus, the westerly flow was considerably weaker than normal between 30° and 50° N. in the eastern Atlantic.

The temperature anomaly pattern for the month (Chart I) was very similar to that of the previous month (see Chart I in March 1950 Monthly Weather Review). This persistence was directly associated with the general persistence of the basic circulation pattern over North America during March and April. Thus, above-normal 700-mb. heights in Canada and below-normal heights along the Canadian-United States border and throughout the eastern two-thirds of the United States resulted in repeated outbreaks of cold Canadian Polar air into central and eastern United States. At sea level a well-defined ridge extended from the Dakotas southeastward through Iowa and Missouri into the Southeast (Chart VI). Pressures in this ridge were more than 2 mb. above normal from the Canadian border to the Gulf coast (Chart II inset). The isopleths of sea level pressure anomaly show that the flow out of Canada was considerably stronger than normal in Minnesota and Wisconsin where the coldest temperature anomalies in the entire United States were observed—as much as 10° F. below normal, the coldest on record in that area for April. Chart VI indicates that this cold air at sea level came from the northeast, almost directly from the frozen Hudson Bay region.

The anticyclone tracks (Chart II) show that the highs associated with this cold weather originated in both the Pacific Ocean and Canada, and generally moved southeastward through the middle sections of the country (on the average near the mean sea level ridge mentioned above). A few high cells also moved eastward across Canada. The one which started in the Yukon on the 5th was very intense and extensive in a meridianal direction, and was responsible for a very severe outbreak of cold air in all of the United States east of the Rockies. The highs moving into the Pacific Northwest contributed to the cold weather experienced there during April. In addition, the stronger-than-normal onshore flow of cool Pacific air aloft mentioned earlier and the abnormally high monthly mean sea level pressure (Charts VI and II inset) were associated with these subnormal temperatures. Temperatures in New England and along most of the immediate east coast as far south as the Carolinas averaged very close to normal. This area was close to and slightly east of the 700-mb. trough, and was located under a weak southerly flow relative to normal. Above-normal temperatures were confined to the Southwest where 700-mb. heights were above normal and where the thermal low at the surface was very well developed (Charts VI and II inset).

Precipitation was generally deficient in the West and throughout the central and southern Plains (Chart V and inset). This was associated with general ridge conditions at 700 mb. and the abnormally strong northwesterly flow east of the ridge. However, rainfall was generally heavy in coastal sections of Washington due to the strong onshore flow from the trough in the eastern Pacific. The rapid fall-off in the precipitation to lighter-than-normal amounts in eastern Washington may be ascribed to the influence of the anticyclonic circulation aloft. Above-normal precipitation in Montana and the Dakotas occurred with northwesterly flow aloft (fig. 1) and easterly and southeasterly flow at the surface (Chart VI). Much of this precipitation was in the form of snow (Chart VII) and was caused primarily by Pacific maritime Polar air overrunning the cold Polar domes banked against the Continental Divide. At many points in this region, the amounts of snow for this month were at least as great as the amounts in either January or February 1950.

In the Great Lakes region precipitation amounts were heavier than normal under the pronounced cyclonic circulation aloft in the vicinity of the deep trough at 700 mb. (fig. 1). The cyclone paths in Chart III indicate that surface cyclonic activity was frequent in this region during April. Further evidence of this cyclonic activity may be found on the mean sea level map (Chart VI) where a pronounced low was centered in western Michigan with sharp cyclonic curvature throughout the surrounding region. It is also interesting to note that a center of low percentage of clear sky for the month was located in southern Michigan close to the sea level low center and in the region of heavy precipitation (Chart IV). Lighter-than-normal precipitation over much of the Appalachians and along the east coast as far south as the Carolinas was related to the unusual tilt of the upper level trough in a northwest-southeast direction.[2] This tilt was probably associated with the fact that east coast storms moved either away from the coast in a straight easterly direction or northward at a considerable distance from the coast (Chart III) so that few cyclones passed through this entire region. The several east coast cyclones that developed in southern New England and off the New Jersey coast between the 9th and 13th produced snowfall in southern sections of New England and New York (Chart VII) which exceeded the total amounts for January 1950. However, the amount of this snowfall was very small in terms of the normal April precipitation for this area.

The heavy rain in the Gulf States is difficult to explain from the cyclone tracks since no low centers passed through that region. It was probably associated with the frequent occurrence of quasi-stationary frontal zones in this region between the cold Polar air and the warm maritime Tropical air. The temperature anomaly in Texas (Chart I) gives some evidence for such a mean frontal zone with above-normal temperatures at Brownsville and Corpus Christi and below-normal temperatures near Houston and Galveston.

[2] Trough tilt on 5-day mean 700-mb. charts was found to be an important parameter related to 5-day precipitation amounts in the Tennessee Valley by Klein. See "An Objective Method of Forecasting Five-Day Precipitation for the Tennessee Valley," William H. Klein, U. S. Weather Bureau *Research Paper No. 29*, April 1949.

METEOROLOGICAL CONDITIONS AFFECTING FLOODS AND HEAVY SNOW IN NORTH DAKOTA AND MINNESOTA, APRIL 24-26, 1950

CHARLES H. PIERCE AND LEWIS C. NORTON

WBAN Analysis Center, U. S. Weather Bureau
Washington, D. C.

INTRODUCTION

Serious floods during the 1950 spring season in the Red River of the North and some of its tributaries were accentuated by variations of weather from one extreme to another. Flooding in the upper reaches of the basin in late March and early April was alleviated somewhat by cooler weather during the first half of April, but during this period new storms added several inches to the snow cover (fig. 1). On April 15 and for the next two days maximum temperatures over the upper (southern) portion of the basin went up to over 60° F., resulting in rapid melting and almost complete disappearance of the snow cover. Extensive flooding resulted in the area of Grand Forks, N. Dak. and northward into Canada, with a second flood crest even higher than the first occurring in May. Adding to the hazard, on April 24, 25, 26, was a heavy snow storm accompanied by high winds and record low temperatures, which added more than a foot of new snow in some areas.

PRECEDENT CONDITIONS

A study of the large scale air flow in the troposphere during the period of April 15–23 will aid in an understanding of some of the factors associated with the heavy snow storm of April 24–26.

A moderately strong meridional circulation maintained a flow of cold air from the north over Canada and the northern United States during the week ending April 15. Within 48 hours however, there was a marked change in the upper-level streamlines. The meridional flow became more zonal in character as shown by the 500-mb. chart of 2200 EST on April 15 (fig. 2). Cold air previously transported from the north was replaced by comparatively warm air brought into the area by the long westerly sweep that extended well out into the Pacific Ocean.

On the 15th, 16th, and 17th the temperatures rose to above 60° F. over most of the watershed of the Red River of the North. The deep snow cover melted with an ensuing run-off of millions of gallons of new water, delaying and augmenting the flood crest as it moved northward. The flood crest at Moorhead, Minn., on April 8 was about 27 feet (flood stage 17 feet). It was not until the 24th–25th of the month that the peak of 43.9 feet (flood stage 30 feet) occurred at Grand Forks, N. Dak. The Red Lake River, which empties into the Red River from the east just upstream from Grand Forks, contributed to the crest there. The 43.9-foot flood peak was the second

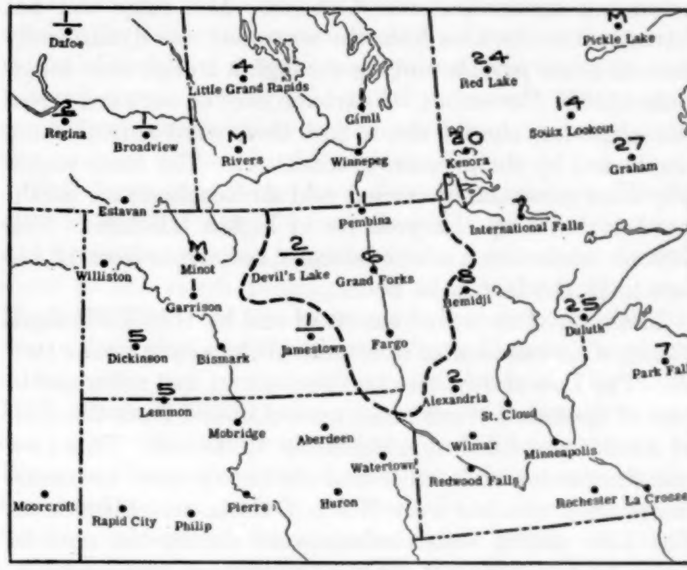


FIGURE 1.—Snow cover chart for 0730 EST, April 15, 1950, for North Dakota, Minnesota, southern Manitoba, southern Saskatchewan, and southwestern Ontario. Dashed line shows the boundary of the water shed in the United States for the Red River of the North.

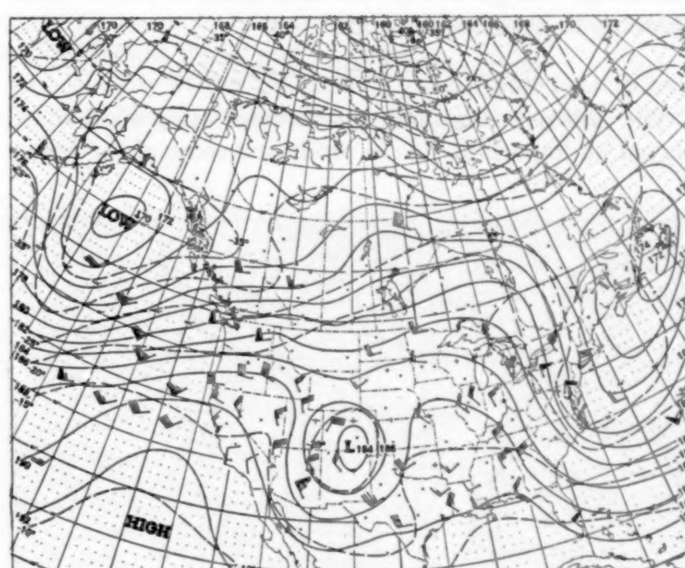


FIGURE 2.—500-mb. chart for 2200 EST, April 15, 1950. Contours (solid lines) at 200-ft. intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are drawn for intervals of 5° C. Barbs on wind shafts are for wind speeds in knots; full barb for every ten knots, half barb for every 5 knots, and pennant for every 50 knots.

highest since 1897 when a stage of 50.2 feet was measured. (The crest of 43.9 feet was exceeded by a second crest of 45.7 feet on May 12.)

However, the zonal flow was only transitory. The wave amplitude increased again and at 2200 EST, April 18 (fig. 3) there was a well marked ridge just off the west coast extending northward into Canada. The ridge did not advance into the area from the west, but was dynamically formed as air parcels moving through a trough near longitude 155° W. "overshot" the trough, moved outward across the contours, slowed down and then were turned more northward by the pressure gradient [1]. The more southerly wind presumably carried cold stratospheric air northward to build up the pressure at higher latitudes. The 500-mb. surface at Annette Island, Alaska, rose from 17,430 feet to 18,180 feet in 24 hours.

The ridge then moved eastward and by 1000 EST, April 23 (fig. 4) it was located over central Canada at about 100° W. The Low shown on this chart about 240 miles northeast of Spokane, Wash., had moved inland from the Gulf of Alaska and filled approximately 1,000 feet. This Low was the one which later caused the heavy snow and near-record cold weather over North Dakota and Minnesota. The Low moved east-southeastward during the next 24 hours to a position slightly northwest of Bismarck, N. Dak. (fig. 5). The axis of the warm tongue in the lower troposphere to the east of the Low was then closer in phase with the surface Low. This upper Low was evident on the surface chart for 3 hours earlier, 0730 EST, April 24 (fig. 6) as a small closed cyclonic circulation southwest of Bismarck. However, the major low pressure system was the broad trough along the cold front from northern Missouri to western Oklahoma.

STORM OF APRIL 24–26, 1950

The Low near Bismarck was an interesting whirl which played an important role in producing some of the heavy snow in North Dakota. It developed suddenly in the northern end of an inverted trough, and appeared to be mostly a dynamic development because there was no marked temperature contrast within it. The southwesterly winds in the southeast quadrant were as much a result of the build-up of the ridge over eastern South Dakota as of the deepening near the Low center. It might be argued that there was a warm-type occlusion extending to the east-southeast of the center. The type of development that took place precludes such a front, and also a study of the hourly reports shows a very gradual shift of wind and a slow rise in temperature as the surface trough advanced eastward. By 1330 EST (not shown), a pseudo-warm front might have been introduced on the chart between the easterly current over Minnesota and North Dakota and the southwesterly flow over South Dakota.

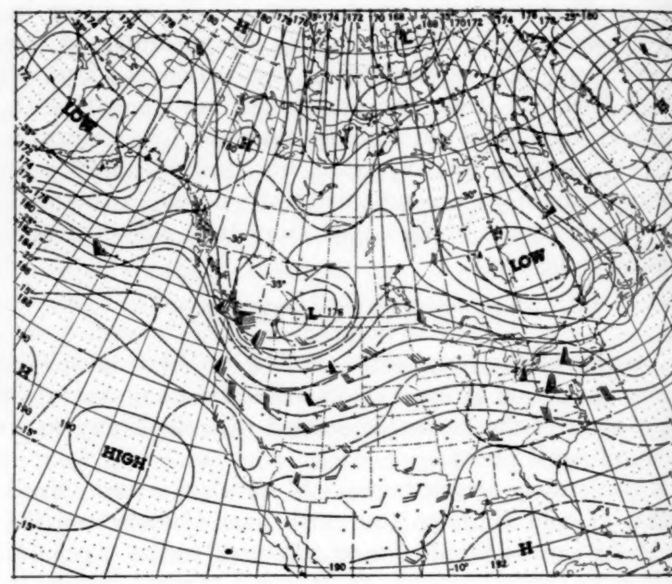


Figure 4.—500-mb. chart for 1000 EST, April 23, 1950.

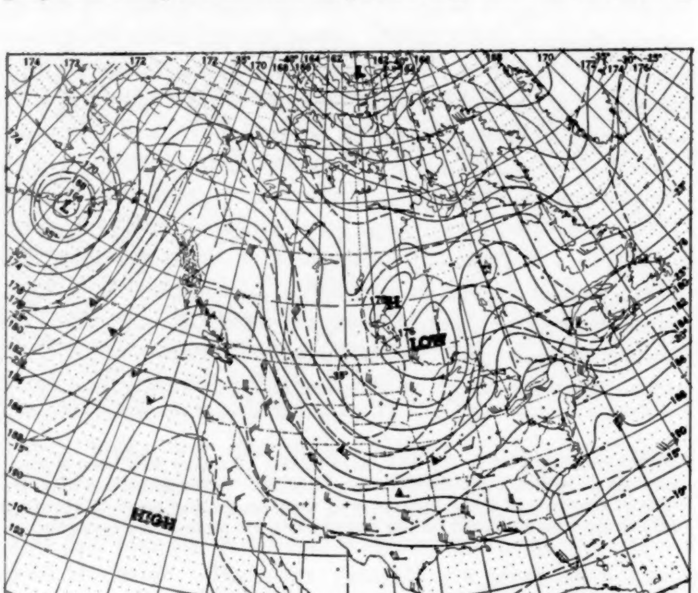


Figure 3.—500-mb. chart for 2200 EST, April 18, 1950.

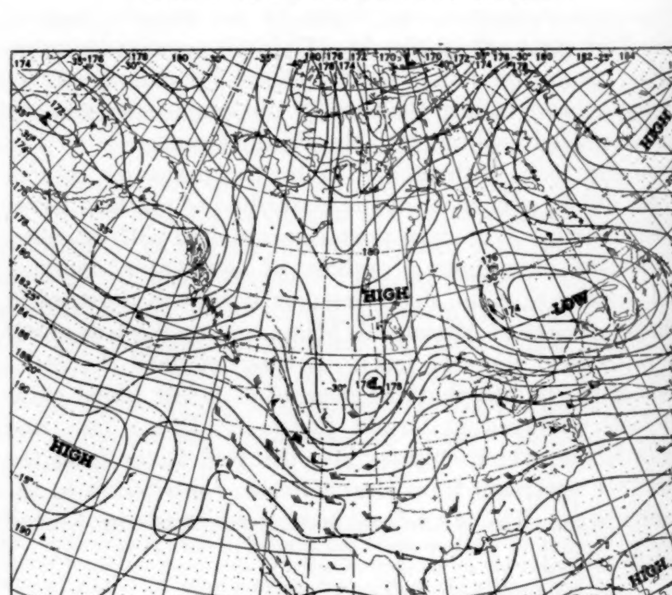


Figure 5.—500-mb. chart for 1000 EST, April 24, 1950.

This would have been a shallow front as it did not appear on the 850-mb. chart, and evidence for it disappeared with nocturnal cooling in the less cloudy air to the south.

The cold front extending from eastern South Dakota into central Kansas (fig. 6) developed earlier over the Rockies as the upper-air trough advanced into that area. Even though the air behind this front was moving down slope, it was cold enough to displace the modified Polar air in the easterly current ahead of it over Kansas and southern Nebraska. Because the easterly current had a steeper horizontal temperature gradient to the north and a more stable lapse rate than the cold air to the west, the cold front was running aloft a short distance over the surface air in northern Nebraska and South Dakota. When it reached the peak of the frontal wave over southeastern Iowa, this front became the mechanism which started the deepening of the major low-pressure system.

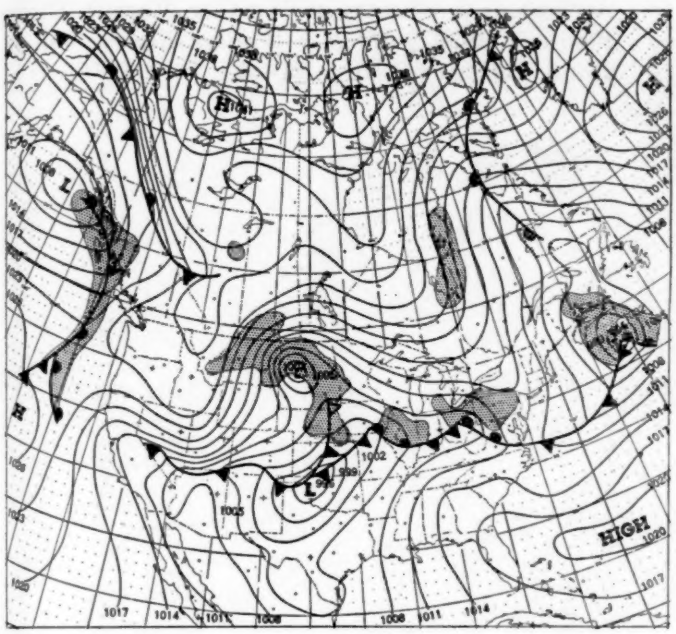


Figure 6.—Surface weather map for 0730 EST, April 24, 1950. Shading indicates areas of active precipitation.

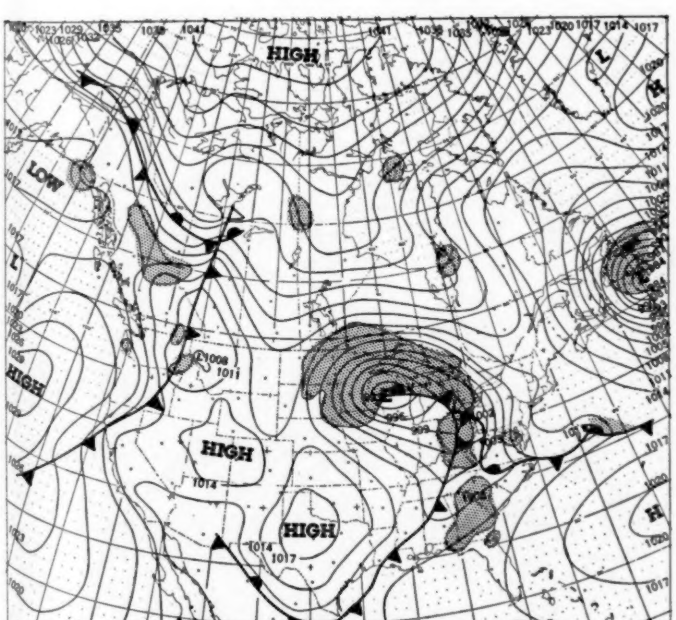


Figure 7.—Surface weather map for 1330 EST, April 25, 1950. Shading indicates areas of active precipitation.

At the time of the map in figure 6, the stage was being set for the Low to begin occluding. Over northern and central Canada a massive anticyclone was building and a broad stream of very cold air on its eastern side poured southward across Hudson Bay and then eastward into the complex cyclone in the Missouri Valley.

The deepening of the Low started in western Illinois after 2230 EST, April 24 (not shown). As the deepening and occluding process progressed, the Low center curved more to the north passing west of Rockford, Ill., and Madison, Wis. At the same time the cyclonic whirl in the cold air that developed over North Dakota decreased in intensity and moved almost straight east. By 1330 EST, April 25 (fig. 7) the two Lows had combined into one center with a pressure of 992 mb. to the southwest of Wausau, Wis. The Low center then moved north-northwestward to the vicinity of Park Falls, Wis., where it became stationary for a period of 9 hours. It then drifted off to the northeast and filled slowly.

Throughout this period the snow, which had begun to fall during the night of April 23, continued to accumulate on the ground. It was not until the morning of April 27 that the snow fall ceased. By that time there was a snowcover of four inches to over one foot on the ground across North Dakota and northern Minnesota. The snow and subfreezing temperatures, which were driven by winds up to 40 m. p. h., increased the difficulty of evacuation around Grand Forks and northward.

In its early stages the surface low-pressure system had a rather complicated structure. However, aloft above

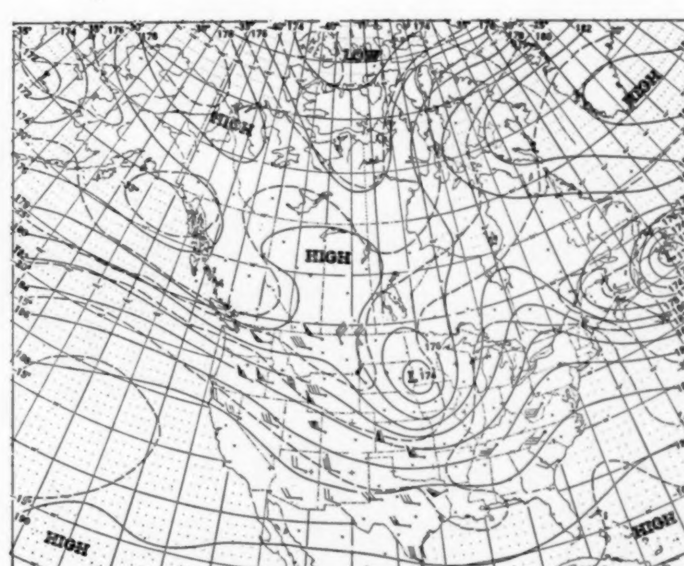


Figure 8.—500-mb. chart for 1000 EST, April 25, 1950.

the 850-mb. surface it was a simple closed Low with a tongue of warm moist air on its eastern side and a flow of cold air on its western periphery. The upper-level Low decelerated once it reached North Dakota, moving only 300 miles from April 24 to April 25 (figs. 5 and 8). Thus the protracted snowfall over the Red River Basin at the beginning of the period was caused by lifting in the middle troposphere of the warm moist air from the south and later the southeast over the colder surface air. During the last two days, the snow was more in the form of showers produced in the unstable cold air by convergence in the area to the rear of the storm where the cyclonic curvature of the isobars was marked.

The flood in the Red River Valley of the North caused higher crests at some stations than had been observed during the past 50 years. At Pembina, N. Dak. (near the international boundary) the river rose until the end of the month when it crested at 51.7 feet, the highest since 1826. This crest and another slightly higher on May 14 caused severe damage at Winnipeg, Manitoba. At the time of this writing (June 6) the river had not returned to normal and the total loss from this flood will not be known for many months.

REFERENCE

1. H. B. Wobus and L. C. Norton, "Some Synoptic Aspects of a Change in Weather Regime During February 1950," *Monthly Weather Review*, vol. 78, No. 2, February 1950, p. 31–40.

U. S. GOVERNMENT PRINTING OFFICE: 1950

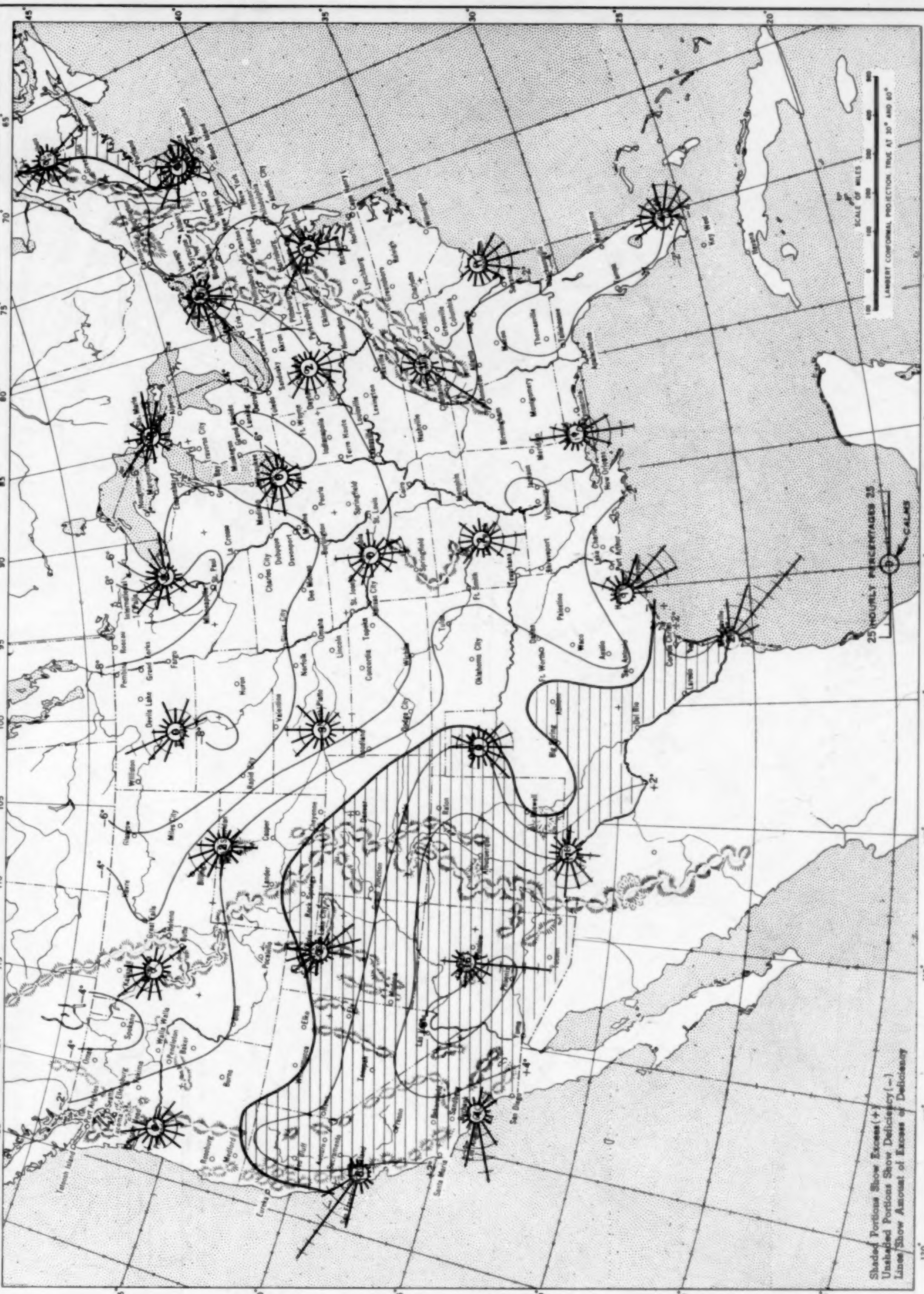
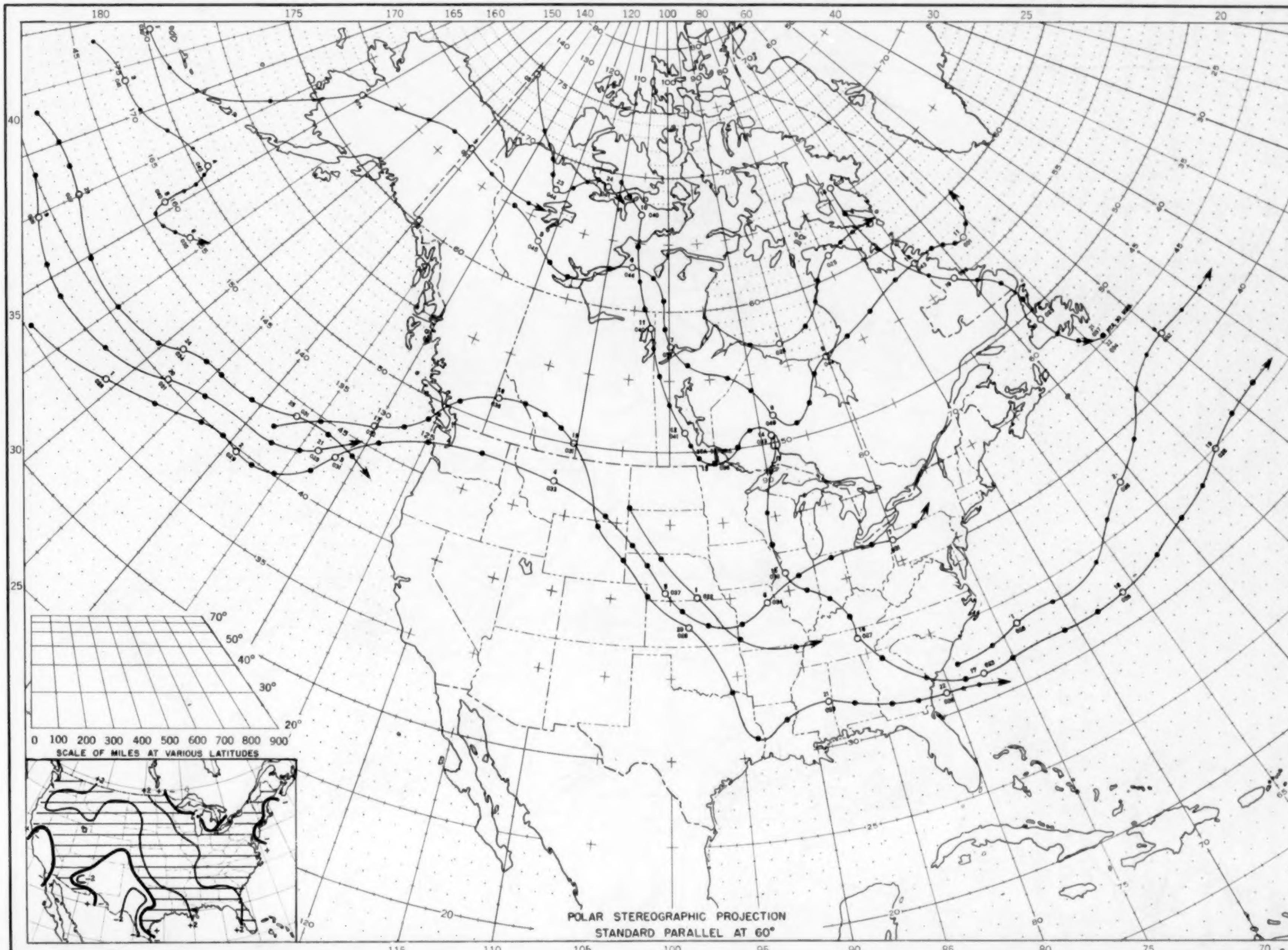


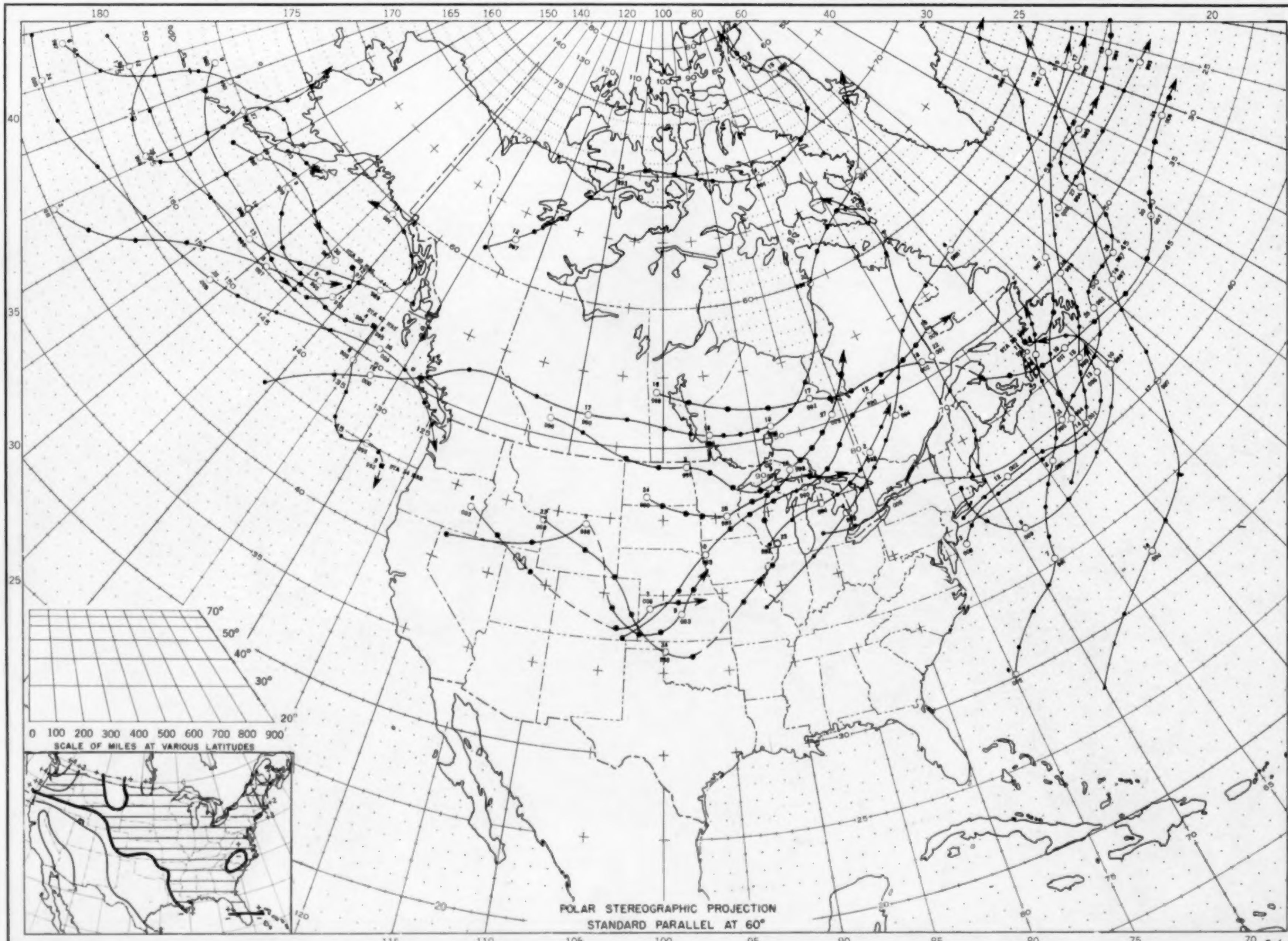
Chart I. Departure (°F.) of the Mean Temperature from the Normal, and Wind Roses for Selected Stations, April 1950

Chart II. Tracks of Centers of Anticyclones, April 1950. (Inset) Departure of Monthly Mean Pressure from Normal



Circle indicates position of anticyclone at 7:30 a. m. (75th meridian time). Dots indicate intervening 6-hourly positions. Figure above circle indicates date, and figure below, pressure to nearest millibar. Only those centers which could be identified for 24 hours or more are included.

Chart III. Tracks of Centers of Cyclones, April 1950. (Inset) Change in Mean Pressure from Preceding Month



Circle indicates position of cyclone at 7:30 a. m. (75th meridian time) Dots indicate intervening 6-hourly positions. Figure above circle indicates date, and figure below, pressure to nearest millibar. Only those centers which could be identified for 24 hours or more are included.

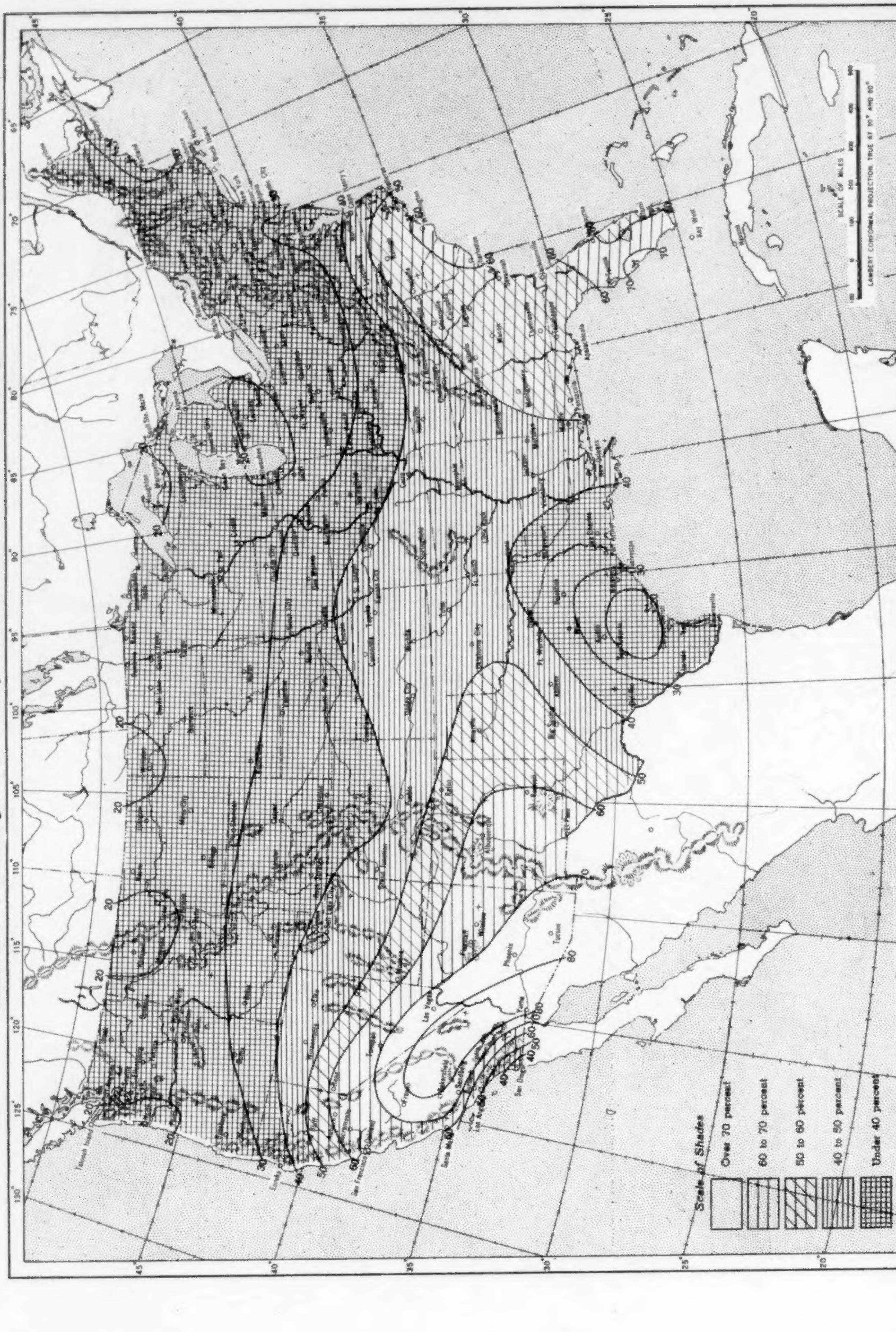


Chart IV. Percentage of Clear Sky Between Sunrise and Sunset, April 1950

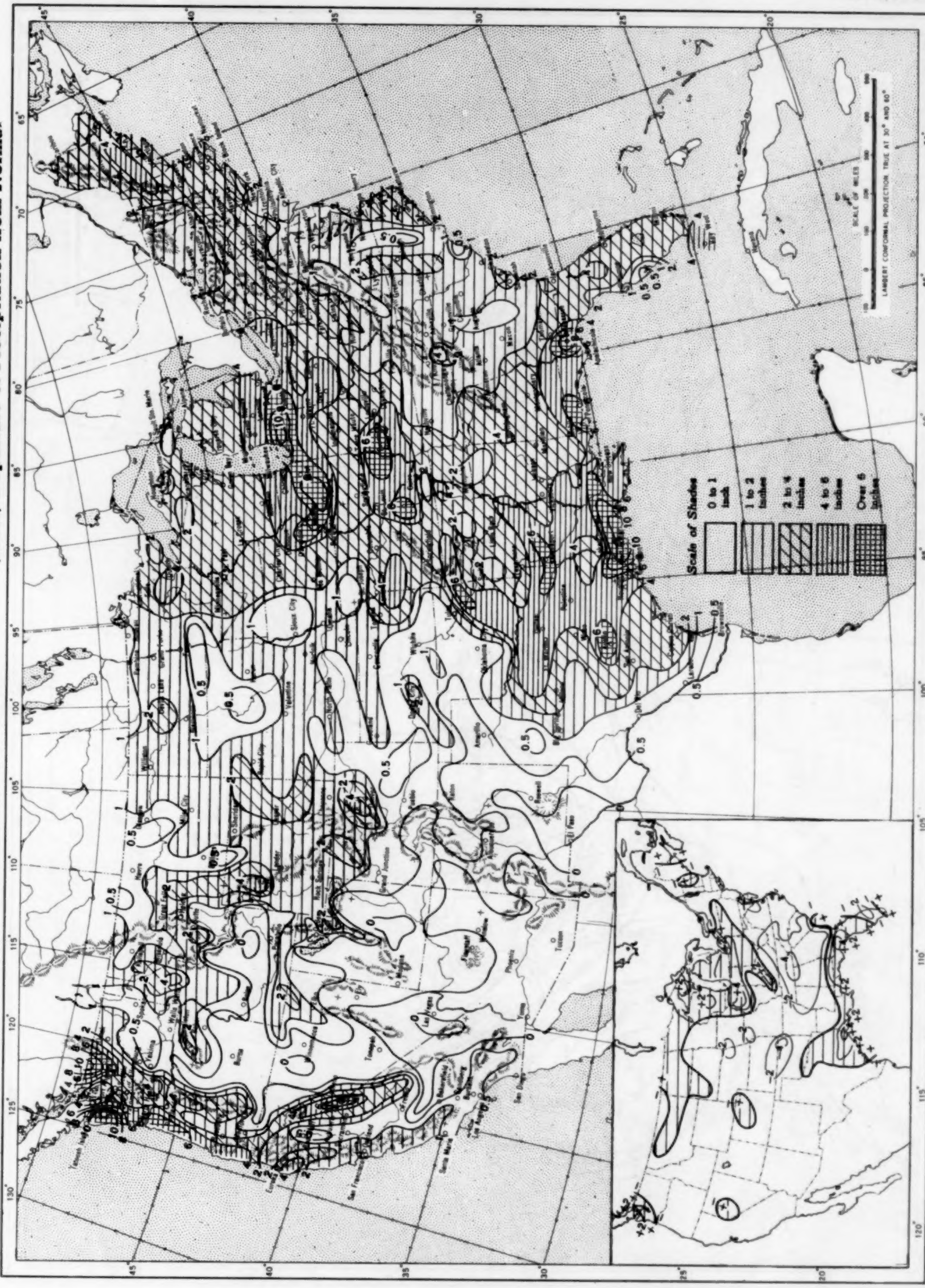


Chart V. Total Precipitation, Inches, April 1950. (Inset) Departure of Precipitation from Normal

Chart VI. Mean Isobars (mb.) at Sea Level and Mean Isotherms (°F.) at Surface., April 1950

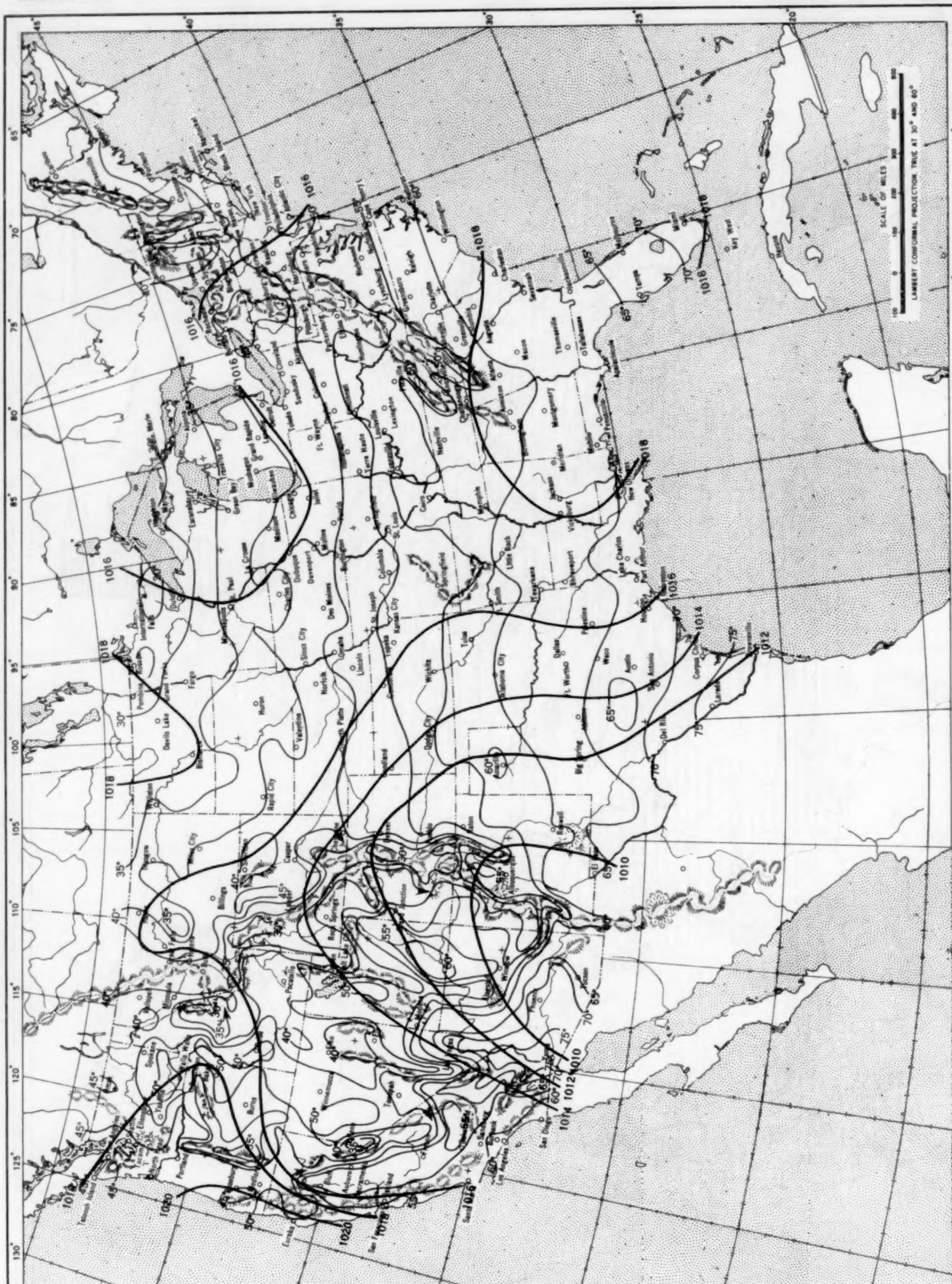
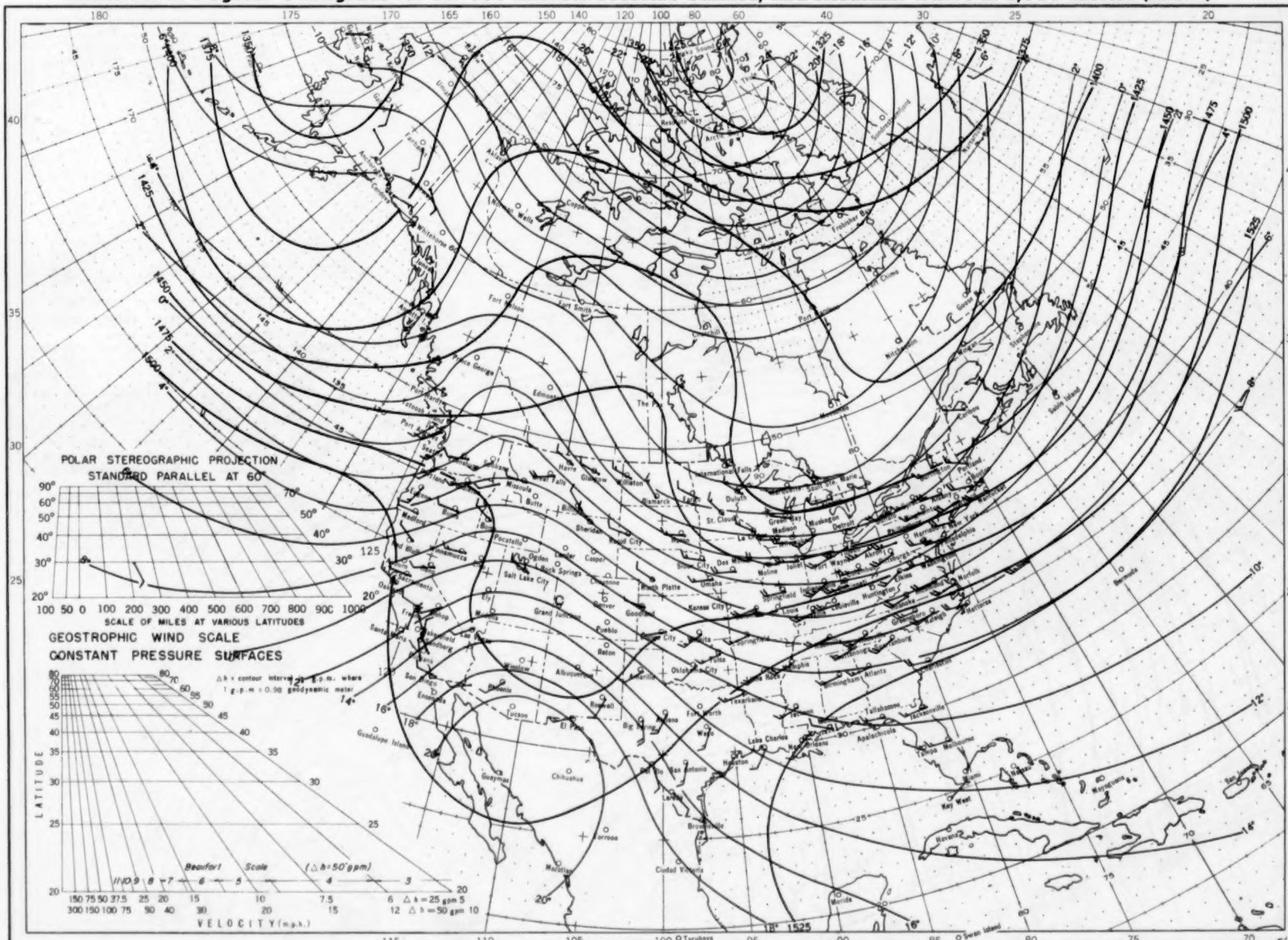


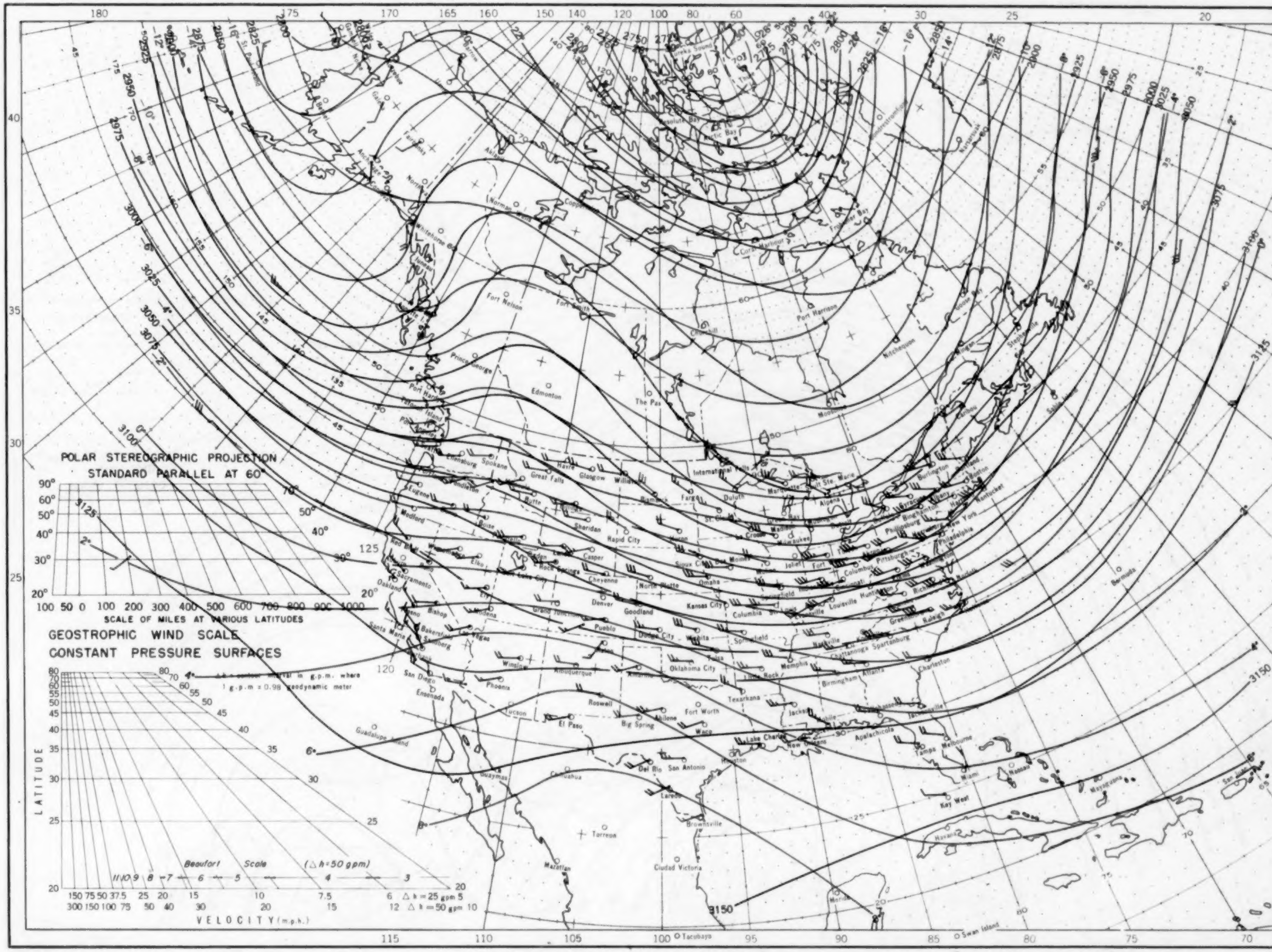
Chart VII. Total Snowfall, Inches, April 1950.

Chart VIII, April 1950. Contour Lines of Mean Dynamic Height (Geopotential) in Units of 0.98 Dynamic Meters and Mean Isotherms in Degrees Centigrade for the 850-millibar Pressure Surface, and Resultant Winds at 1,500 Meters (m. s. l.)



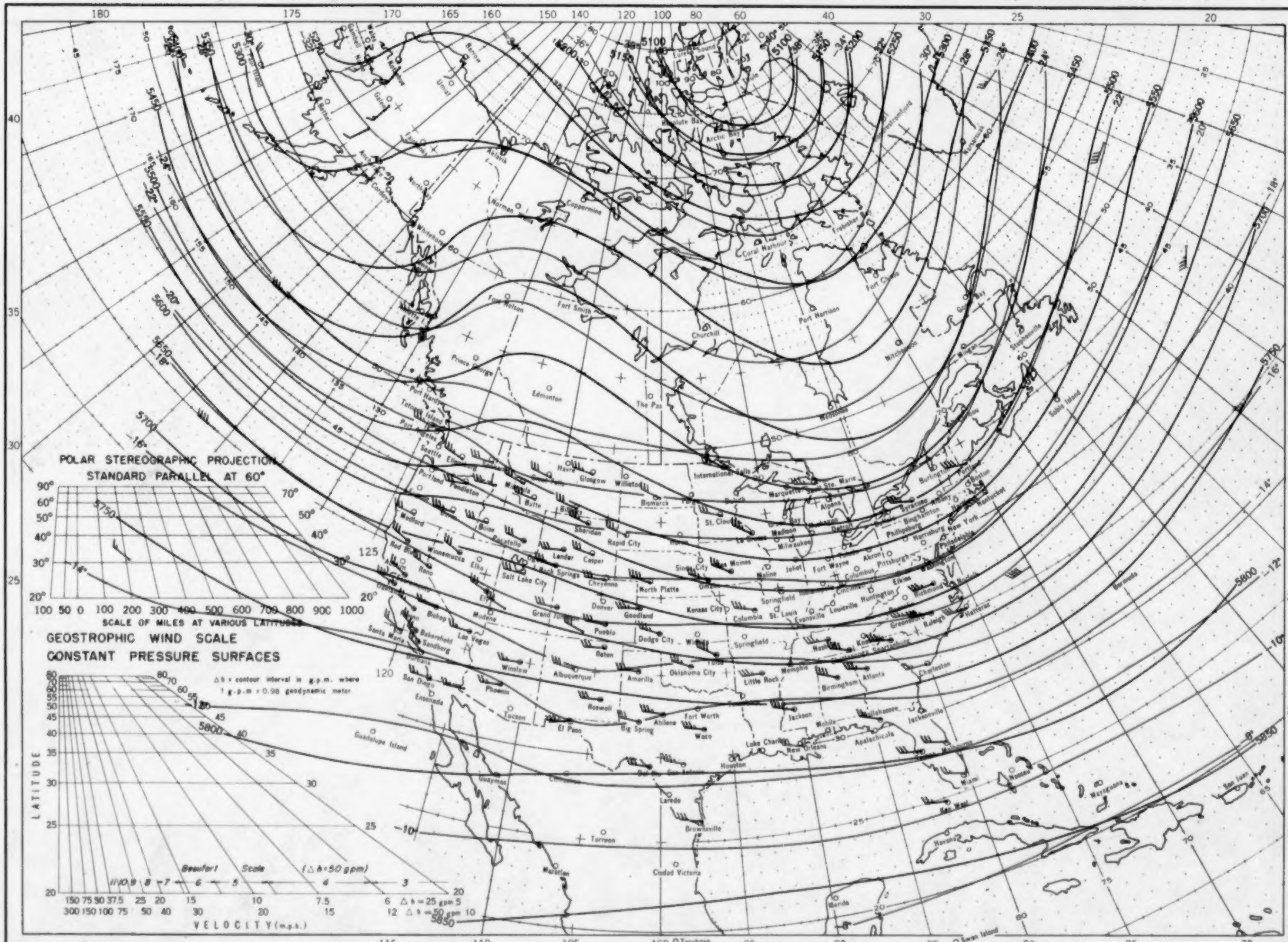
Contour lines and isotherms based on radiosonde observations at 0300 G. C. T. Winds indicated by black arrows based on pilot balloon observations at 2100 G. C. T.; those indicated by red arrows based on rawins taken at 0300 G. C. T.

Chart IX, April 1950. Contour Lines of Mean Dynamic Height (Geopotential) in Units of 0.98 Dynamic Meters and Mean Isotherms in Degrees Centigrade for the 700-millibar Pressure Surface, and Resultant Winds at 3,000 Meters (m. s. l.)



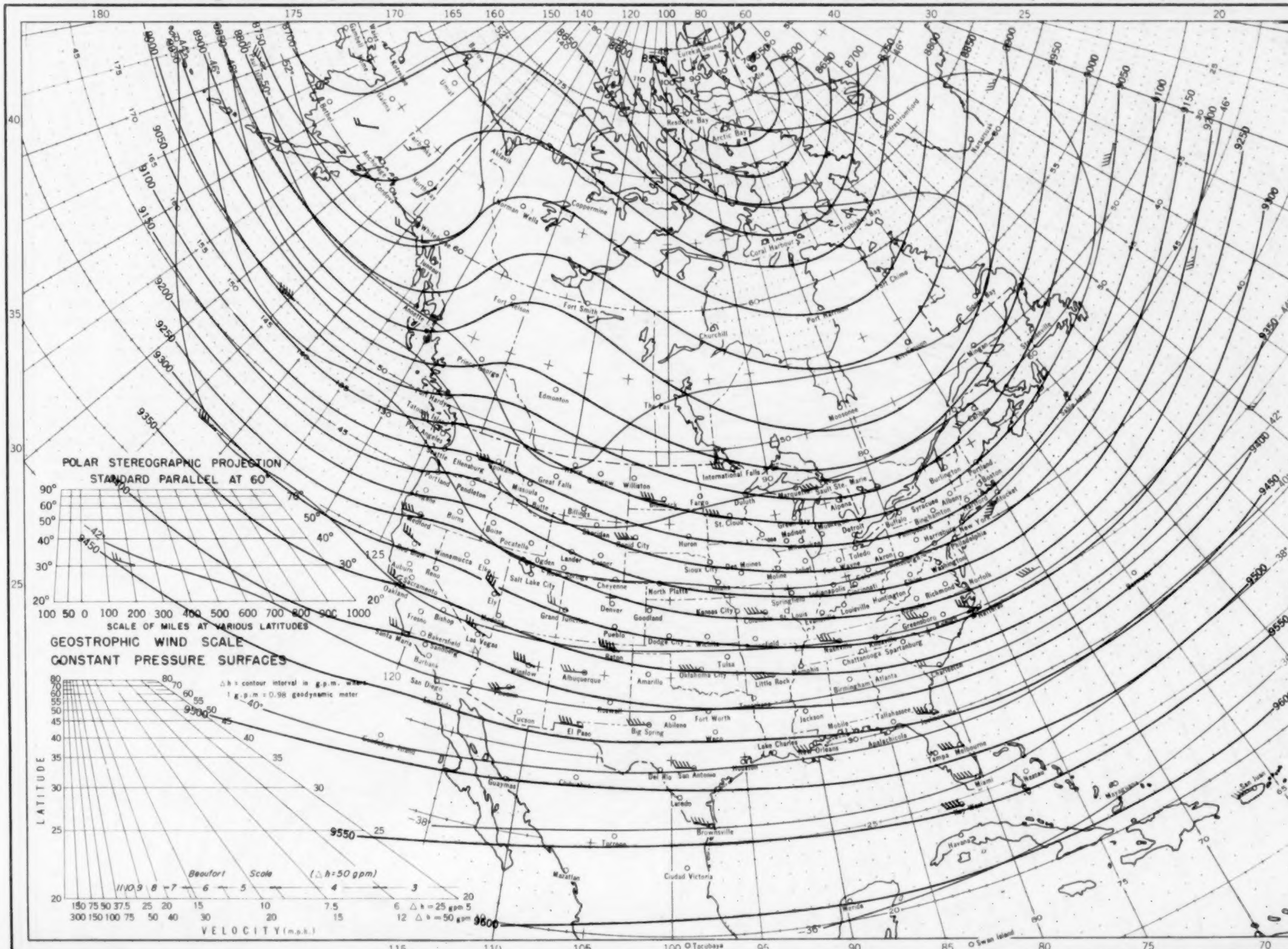
Contour lines and isotherms based on radiosonde observations at 0300 G. C. T. Winds indicated by black arrows based on pilot balloon observations at 2100 G. C. T.; those indicated by red arrows based on rawins taken at 0300 G. C. T.

Chart X, April 1950. Contour Lines of Mean Dynamic Height (Geopotential) in Units of 0.98 Dynamic Meters and Mean Isotherms in Degrees Centigrade for the 500-millibar Pressure Surface, and Resultant Winds at 5,000 Meters (m. s. l.)



Contour lines and isotherms based on radiosonde observations at 0300 G. C. T. Winds indicated by black arrows based on pilot balloon observations at 2100 G. C. T.; those indicated by red arrows based on rawins taken at 0300 G. C. T.

Chart XI, April 1950. Contour Lines of Mean Dynamic Height (Geopotential) in Units of 0.98 Dynamic Meters and Mean Isotherms in Degrees Centigrade for the 300-millibar Pressure Surface, and Resultant Winds at 10,000 Meters (m. s. l.)



Contour lines and isotherms based on radiosonde observations at 0300 G. C. T. Winds indicated by black arrows based on pilot balloon observations at 2100 G. C. T.; those indicated by red arrows based on rawins taken at 0300 G. C. T.